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Contributions
to
Practical Science
by Walter R. Johnson

EXPERIMENTAL INQUIRIES

RESPECTING

HEAT AND VAPOR;

WITH SOME

PRACTICAL APPLICATIONS:

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EXPERIMENTAL INQUIRIES, &c.

To account for the sudden explosions which sometimes occur in steam boilers, one hypothesis assumes that the metal, by undue exposure to the fire, and by a deficiency in the supply of water, becomes intensely heated, and thereby affords a *source of heat* ready to act with great rapidity on any new portion of water which may be injected, or otherwise brought into contact with the heated surface. Whether the water be thrown up by ebullition, or caused to flow over the hot part of the boiler, by some *change in the position* of the latter, will be of little consequence to the result, so long as we are sure of the presence of the dangerous generator.

The construction of many steam boats, or rather the arrangement of their boilers, favors the presumption that a mere change of position has sometimes caused an explosion of the nature now alluded to.

In the boats which navigate our western waters, eight or nine boilers of a cylindrical form, thirty inches in diameter, and about fourteen feet long, are laid side by side, lengthwise of the boat, so that allowing for interstices, from twenty two to thirty feet of the breadth of the deck, are taken up by the aggregate diameters of the row of boilers. They are almost uniformly constructed with *returning flues* from nine to twelve inches in diameter.

The flue being placed eccentric, with respect to the main cylinder of the boiler, and indeed wholly below its centre, will be entirely immersed when the boiler is half filled with water. The furnace being at one end, the flame passes along the whole length of the boiler

on the outside, and then entering the flue returns to a chimney near the upper or *fire* end. The boilers are all connected together by a pipe forming a water communication at bottom, and by another, forming a common steam passage above their upper surfaces. The lower guage cock is placed from one to three inches above the top of the flue; and so long as the deck remains perfectly horizontal, and the forcing pump for injecting water performs its office, a moderate degree of care, on the part of firemen and engineers, may insure the complete immersion of the flue. But when, from any cause, the boat inclines to either side, there will be a transfer of water through the lower connecting pipe, from the boilers on the elevated, to those on the depressed side of the deck. A large number of passengers collecting on one side would doubtless be sufficient to cause a "heeling" of a foot or more, and this would lay bare the whole of the flue in the upper boiler, and expose more or less surface of iron in every flue and boiler on the elevated side. Every pound of water thus transferred, serves to increase by double its own weight, the tendency of the boat to *careen*, and even after the other causes of unequal depression have ceased to act, the water thus displaced will continue its influence, and will not until after sometime, return to its former level through the pipe of communication. The removal of water from the part of the usual generating surface of metal, will cause the supply of steam to be diminished, so that the *engine* may appear to labor, even while the boiler is becoming red hot. This circumstance is known to have preceded some of the most frightful explosions, and it is but the natural result of employing that caloric which ought to be producing steam, in merely raising the temperature of metal, with the incidental effect of heating the steam already generated, considerably above the temperature which belongs to its actual *density*. Not only must those parts of the boilers and flues which are immediately exposed to the fire, become unduly heated, but, owing to the high conducting power of the metal, the upper arch of the cylinder, as well as the lower, will rapidly acquire the temperature due to the source of heat. Some may possibly imagine that since the engine moves slowly for a time in consequence of a deficiency of generating surface, it will only move with the more speed when the accumulated force comes to be added to the regular supply. This might be the case if the excess were furnished with no greater rapidity than the deficiency had occurred. But whether we suppose the hot steam, or the hot metal to furnish

heat of elasticity to the water which flows into the overheated boilers, the supply will be obtained almost instantaneously;—a few seconds, at most, being required to complete the operation of generating, from water of a boiling temperature, all the steam which the iron of the boiler, even when red hot, is capable of producing. In order to determine with some precision, what effect will actually be produced by the metal in such cases, I have performed a series of experiments tending to show the relation between the quantity of steam generated, the weight of the metal, the surface exposed, the time of action and the period of greatest effect. The trials have not been confined to rolled iron alone, but as the results must obviously be effected by the *specific caloric* of the metal, I have extended them also to wrought iron in masses, to cast iron, copper, brass, silver and gold.

These experiments were in part performed during the months of July and August last, when the temperature of the room seldom fell below 80°. This circumstance may, in addition to the other precautions to avoid error in the results, assure us that the change of temperature in the water, between two consecutive experiments, cannot at any time have been sufficient to affect the *quantity* of vapor generated, or the *time* employed in its production. In order to exhibit an approximation to the actual state of the boiler, when in a condition to receive hot water on intensely heated metal, and when, of course, the whole excess of caloric would be employed in giving the elastic form, and none in raising temperature, I procured a cylindrical vessel of tinned iron $19\frac{1}{4}$ inches deep, $7\frac{2}{10}$ inches in diameter, and capable of containing $28\frac{5}{16}$ lbs. of water at 60°. This was furnished with a cover of the same material, and with a wire handle like that of a bucket, for the convenience of suspending it to the beam of a pair of scales. The sides and bottom were covered externally with four successive folds of stout green baize, between each two of which was a *batting* of raw cotton, forming all together a coat of an inch thick. The non-conducting character of this defence may be inferred from the fact that fourteen pounds of water, left in the vessel for fourteen hours, was cooled only from 212°, to 115°, or about 7° per hour, while the temperature of the apartment was 80°; and that in the following twenty five hours, the same portion of water lost only 31°, being found at 84°, though the temperature of the air had in the mean time fallen to 76°. On another occasion, the loss was 9° per hour, or from 212° to 104° in twelve hours, in an apartment where the air was at 60°.

The vessel above described charged with about 15 lbs. of water, was suspended to one hook of the scale beam, while to the opposite was attached the usual pan for weights. The water was then brought to a state of rapid ebullition by heaters, previously plunged for an instant into another vessel of water, to take off any portion of ashes or oxide which might accidentally adhere to the surface. When assured that the water and its container had acquired the boiling temperature, I replaced the cover, and immediately adjusted the weights to an exact counterpoise. The piece of hot metal whose power of producing steam was to be ascertained, was upon removing the cover immediately plunged into the boiling water, and permitted to remain until ebullition ceased. At that instant, the metal was withdrawn, the time noted, the lid adjusted and weight added on the side of the boiler, to compensate for the evaporation of water, until the equilibrium was restored. The experiments were conducted with all due caution to avoid the waste of water, which might ensue from the violent agitation, caused by plunging the metal all at once below the surface. The metal was either lowered gradually into the water, or, when plunged in immediately, was suspended to a wire, attached above to a cover, perforated with numerous holes, to allow the escape of steam, and furnished with a broad funnel shaped rim to receive and return any water which might be projected through the apertures.

In order to avoid communicating to the apparatus a temperature above that of the liquid, the metal was suspended in the water, and not allowed to touch the sides or bottom of the cylinder.

The difficulty of ascertaining with precision the temperatures above the boiling point of mercury, (660°) compelled me to adopt as a standard of comparison, between the different metals, and between different masses of the same metal, a point indicated by the senses. *A barely red heat in daylight* was chosen, as least liable to be misapprehended. Many experiments have been made at temperatures both above and below this point; but as it is probable that the heated parts of boilers are seldom raised above a dull red heat, and that if they were so, their danger, or (perhaps we might say) their *safety*, would arise from the softness and yielding condition of the metal, it has been thought that for practical as well as theoretical purposes, the point above mentioned would be most interesting and important. The experiments to determine the period of *greatest activity* will show, that just below the point of visible redness in daylight, the greatest quantity of steam is generated in a given number

of instants. Such at least is the case when the experiment is performed under ordinary atmospheric pressure. This point therefore, I have termed in the tables the *comparable temperature.* Many of the experiments with wrought iron were performed upon a piece of rolled boiler *plate,* 25½ inches long, by 7½ broad, and $\frac{3}{16}$ of an inch thick, affording a surface (including both faces, and all the edges) of three hundred and ninety five square inches. This was reduced to a coil, for the greater convenience in managing the experiments, but sufficient space was left for the free admission of water to every part of the surface. The first series was intended to exhibit the *quantity* of steam generated without particular reference to the time. The latter however was immediately noted on each occasion, but is not to be taken as the *least* time, in which the mass of metal employed could impart its surplus heat to boiling water. It serves to show that no essential difference was discoverable in the amount of steam produced by metal of the same temperature, whether the latter were immersed all at once, or only covered by degrees with the water, and that, consequently the portion of overheated surface which remained above the water, did not impart to the steam which ascended, any appreciable quantity of its caloric, during the experiment.

FIRST SERIES,

With rolled iron, 395 square inches of surface—water at 212° Fah.; barometer 29.9 inches; the time marked by a pendulum beating seconds; temperature of the apartment from 80° to 85°.

No. of experiment.	Weight of metal in ounces avoirdupois.	Time in seconds.	Weight of steam in ounces avoirdupois.	Decimal part of an ounce of steam from each ounce of metal.	No. of ounces of metal that produced each ounce of steam.	Observed heat of the metal in day light.
1	144.	40	10.75	.0746	13.395	Black heat.
2	144.25	90	16.	.1109	9.016	*Comparable* or dull red in day light.
3	144.25	90	16.	.1109	9.016	*Do.* do. do.
4	144.125	90	16.	.1110	9.008	*Do.* do. do.
5	144.125	90	16.	.1110	9.008	*Do.* do. do.
6	144.	70	16.5	.1145	8.727	Slight incr'se in redness, plunged sooner.
7	144.	150	19.75	.1371	7.291	Clear red, immersed by degrees.
8	144.25	120	20.	.1386	7.2125	Bright red.
9	144.	90	21.	.1458	6.857	Brighter red.
10	144.	90	22.5	.1562	6.400	Very bright; metal yielding easily.

The 2d, 3d, 4th and 5th experiments, present a remarkable coincidence of results, and prove that at the temperature of comparison, nine pounds of wrought iron will generate one pound of steam, under atmospheric pressure. Subsequent series will show, that, but for the caution necessary to avoid waste, this effect might have been produced in twenty-five or thirty seconds, instead of the times above noted.

SECOND SERIES,

With wrought iron cylinders, 6 inches long, and 1.7 inches in diameter; surface, 38 square inches, including that of the hook; water kept at 212°.

No. of experiment.	Ounces avoirdupois of metal.	Time in seconds.	Ounces of steam produced.	Decimal part of an ounce of steam to one ounce of metal.	Ounces of metal for each ounce of steam.	HEAT OBSERVED.	REMARKS.
1	62.5	42	4	.0640	15.625	Black.	Iron immersed at once.
2	62.5	45	4	.0640	15.625	Do.	Do. do.
3	62.5	45	5.25	.0840	11.904	Do.	Do. do.
4	62.5	48	5.5	.0880	11.363	Do.	Do. do.
5	63	120	7	.1111	9.000	Dull red; comparative temp.	Do. by degrees.
6	63	120	7	.1111	9.000	Do.	Do. do.
7	63	120	7	.1111	9.000	Do.	Do. do.
8	63	120	7	.1111	9.000	Do.	Do. do.
9	63	80	7.25	.1150	8.689	Do.	Do. quickly but not *at once.*
10	62.5	90	7.75	.1240	8.064	Fair red.	Do. do.
11	63	150	8	.1270	7.875	Do.	Do. by degrees.
12	63	150	8	.1270	7.875	Do.	Do. do.
13	62.25	100	9.5	.1365	6.552	Full red.	Do. at once.
14	62.25	120	10.5	.1686	5.928	Bright red.	Do. do.

The striking correspondence in the results of those experiments in the above series, which purport to have been made at the *comparable temperature* (No.'s 5, 6, 7, 8 and 9) with the analogous ones in the *first series*, render it evident that in this form, as well as in that of the plate, the amount of steam generated by any portion of wrought iron at a dull red heat, bears a direct relation to the weight of metal, being one pound of steam to every nine pounds of iron.

THIRD SERIES,

With cylinders of cast iron of different weights, and at different temperatures; water at 212°. The surface exposed in each experiment, is indicated in a separate column.

No. of experiment.	Weight of metal employed, in ounces.	Time in seconds.	Ounces of steam produced.	Dec. part of an oz. of steam to 1 oz. metal.	Ounces of metal to 1 of steam.	Square inches of surface.	HEAT OBSERVED.	REMARKS.	
1	60	30	2.25	.0375	26.666	37.69	Black.	Immersed	at once.
2	168	60	6.75	.0401	24.888	86.25	Do.	Do.	do.
3	152	80	7.	.0460	21.714	77.47	Do.	Do.	by degrees.
4	60	50	3.375	.0562	16.000	37.69	Do.	Do.	at once.
5	168	90	14.25	.0848	11.789	86.25	Do.	Do.	do.
6	152	135	13.75	.0904	11.054	77.47	Do.	Do.	do.
7	60	55	5.5	.0916	10.909	37.69	Do.	Do.	do.
8	60	55	5.5	.0916	10.909	37.69	Do.	Do.	do.
9	168	105	15.5	.0922	10.838	86.25	Do.	Do.	do.
10	168	106	16.	.0952	10.500	86.25	Do.	Do.	do.
11	60	60	6.5	.1083	9.230	37.69	Low red in the dark.	Do.	do.
12	60	55	6.75	.1125	8.888	37.69	Do.	Do.	do.
13	60	55	6.75	.1125	8.888	37.69	Do.	Do.	do.
14	61	90	7.	.1147	8.714	37.69	*Comparable*, (dull red in day light.)	Do.	by degrees.
15	168	300	19.5	.1160	8.618	86.25	Do.	Do.	do.
16	168	300	19.5	.1160	8.618	86.25	Do.	Do.	do.
17	61	105	7.25	.1185	8.413	37.69	Do.	Do.	do.
18	61	105	7.5	.1229	8.133	37.69	Do.	Do.	do.
19	61	120	7.5	.1229	8.133	37.69	Do.	Do.	slowly.
20	152	300	19.	.1250	8.000	77.47	Do.	Do.	do.
21	152	300	19.	.1250	8.000	77.47	Do.	Do.	do.
22	152	300	19.	.1250	8.000	77.47	Do.	Do.	do.
23	60	70	7.75	.1291	7.741	37.69	Brighter red.	Do.	almost instantly.
24	152	300	21.	.1316	7.238	77.47	Clear red.	Do.	gradually.
25	61	90	8.	.1331	7.625	37.69	Do.	Do.	in few seconds.
26	61	120	8.5	.1393	7.176	37.69	Do.	Do.	gradually.
27	168	180	23 5	.1398	7.149	86.25	Full red.	Do.	do.
28	60	75	8.5	.1416	7.058	37.69	Do.	Do.	at once.
29	151	300	22.	.1457	6.864	77.47	Do.	Do.	gradually.
30	61	120	9.	.1475	6.727	37.69	Bright red.	Do.	do.
31	152	180	29.	.1908	5.241	77.47	Do.	Do.	in few seconds.
32	60	105	11.5	.1916	5.217	37.69	Very bright.	Do.	rapidly.
33	152	270	32.75	.2154	4.641	77.47	Do.	Do.	gradually.
34	152	360	34.	.2237	4.470	77.47	Do.	Do.	slowly.

It appears from the preceding table, that the least amount of steam given by any of the experiments, was that of No. 1, where, under the head of *decimal parts*, we find $3\frac{3}{4}$ per cent.; and the greatest amount was that of No. 34, where the same column exhibits $22\frac{37}{100}$ per cent. In the latter case, $4\frac{47}{100}$ lbs. of metal gave a pound of steam, while in the former, $26\frac{2}{3}$ lbs. were required for that purpose.

A comparison of the third series with the two preceding, will show that at the *comparable temperature*, cast iron is capable of generating more steam for each unit of weight in the metal, than wrought iron. It may possibly be found that the temperature of *luminousness* in the two kinds, is different. But from heating similar masses of the two, side by side in the same exposure, and observing no difference in the time of coming to redness, I have been led to attribute the difference to a difference in the specific caloric of cast and wrought iron; a circumstance which would probably be sufficiently accounted for, by the difference in their constituent elements.

The mean amount of cast iron to each pound of steam, in the nine experiments marked *comparable*, is $8\frac{281}{1000}$ lbs. We might probably assume $8\frac{1}{4}$ as the number, without material error.

From the data above furnished, we may readily calculate the quantity of steam, of atmospheric pressure, which would be generated by any known quantity of iron that should become red hot. Thus, should a boiler twenty feet long and thirty inches in diameter, with a returning flue one foot in diameter, be constructed of iron one fourth of an inch thick, the exterior shell would give a curved surface of 157 square feet, and as the specific gravity of good boiler iron is 7.770, it must weigh 10 pounds 2 oz. to the square foot. The whole exterior cylinder would therefore weigh 1582 pounds, exclusive of any allowance for rivets and for double thickness at the joints. The weight of the interior shell or flue will be 636 pounds. As the fire is supposed to act on *one half* of the outer shell, and on the *whole* of the flue, there would, in case of the heeling of a boat, sufficiently to throw all the water out of one boiler, be no less than $636+\frac{1582}{2}=1427$ pounds of iron exposed to the direct action of the fire, and liable to become red hot. By the *first series*, we see that one pound of atmospheric steam will be generated from water at 212° by every nine pounds of iron, at a low red heat, in day light; consequently, the metal above supposed would be sufficient to produce $\frac{1427}{9}=158\frac{5}{9}$ lbs. of steam from water at 212°, whenever a change of position should favor its influx in sufficient quantity to cover, either by actual submersion, or by violent agitation, the surfaces of the flue and lower arch of the boiler. To calculate the effect of this weight of vapor, we must compare its bulk with the *steam-room* left in the boiler. The whole interior capacity of the latter is but 82.4 cubic feet; but

in the condition of things now supposed, a small part only of this space is occupied by water.

The bulk of steam becomes known by comparing its specific gravity with that of the water from which it is formed. Thus, assuming the specific gravity of common air, at 60° Fah. to be .00122 of that of water at the same temperature, as determined by Biot & Arago, the specific gravity of steam compared with air at 60° being .481 to 1, the specific gravity of steam compared with *water at that temperature*, is .00058682. As $158\frac{5}{9}$ lbs. of water at 60° measure $\frac{158.5}{62.5}=2.536$ cubic feet, the *atmospheric steam*, which can be obtained from it will be $=2.536\div.00058682=4321$ cubic feet; which, divided by the capacity of the boiler, gives $\frac{4321}{82.4}=52\frac{362}{824}=52\frac{3}{7}$, nearly, for the number of atmospheres of pressure, supposing the whole to be condensed and confined in the single boiler, within which we have shown that it may be generated. This would give 786 lbs. to the square inch. But upon the supposition that while heat continues to be applied to the boiler, from which the water is drained, its connexion with others remains uninterrupted, nearly the usual pressure will be maintained within it. This pressure may be stated at 8 atmospheres; so that by adding the $52\frac{3}{7}$ derived from the over-heated metal we should have no less than $60\frac{3}{7}$ atmospheres or 906 lbs. to the square inch for the resulting elasticity. This is upon the assumption that steam obeys the same law in regard to its relative bulk and elasticity, as that which governs atmospheric air. But if it do not follow that law, there is no probability whatever that the pressure would be *less* than in the direct ratio of the density.

It is true that if only one boiler in a range were to become empty and exposed to excessive heat, at the same time, the quantity of steam just calculated, would be, in part, distributed through the connecting pipe, to the others, at the moment of its production, which would diminish in a measure the pressure in the overheated boiler. It may be said on the other hand, that the overheating of the outer shell will never be confined to the lower arch, nor to a single boiler in a range; and it is evident that the *lower* boilers in a boat must in the cases supposed want *steam room* in proportion as the *upper* want water; and that the connecting pipe could not, as generally constructed, convey away the steam so fast as it

would be produced. The boiler which had been most remote from the wharf, has generally sustained the injury, in explosions that have occurred immediately after putting off.

Before proceeding to the detail of experiments on other metals, I think it proper to present the following series of results, in which my main object was to ascertain, accurately, the rapidity of cooling of iron from incandescence down to 212°, taking into consideration the temperature of the water, both at the beginning and end of the experiment, its weight in some cases, and the relation, in all cases, between the weight of metal and the amount of its generating surface. These experiments were performed in an apparatus similar to that described in my former communication, but furnished with an attached thermometer to mark with accuracy the temperatures attained. The result, as will be seen, is, that the times approximate to an inverse proportion to the generating surface. This proportion will not be found to obtain, where part of the heat was employed in raising temperature, and a part in generating steam. The time demanded for cooling a given mass of metal from redness to 212°, by the latter process, must be greater than by the former, both because the temperature of the liquid, which is to receive heat, is greater, and the difference between it and the metal less, and because the surface of the iron is momentarily denuded of water and prevented from acting by a constant and uniform communication. The temperature, in a few instances, was calculated by multiplying the weight of water by the number of degrees through which it was heated, and dividing the product by the weight of metal multiplied into its specific heat. To the quotient was, of course, added 212°, the temperature at which the metal was withdrawn after every trial.

FOURTH SERIES.

Showing the time in which iron, in a state of incandescence, may be reduced to the boiling temperature, either by heating water from different points, by generating steam, or by both operations in succession.

Quality and form of the masses of metal.	No. of experiment.	Weight of water.	Relation of *surface to weight* of metal.	Temperature of water at the beginning.	Temperature attained at the end.	Time in passing from incandescence to 212°.	Calculated temperature.	*Remarks on observed temperatures.*
		lbs.	*oz. sq.in.*	°	°	″	°	
Cast iron cylinder, 168 oz. 86.25 sq. in.	1	26	1 : .513	60	138	77	1805	Very bright red.
	2	unc.	1 : .513	60	140	81		Comparable.
	3	unc.	1 : .513	120	212	71		Clear red.
Cast iron cylinder, 150 oz. 77.25 sq. in.	4	15	1 : .515	55	190	126		Bright red.
	5	21.5	1 : .515	60	144	117	1801	Very bright red.
	6	unc.	1 : .515	60	212	114		Bright red.
	7	11	1 : .515	76	180	95	1218	Above comparable.
Cast iron cylinder, 60 oz. 37.5 sq. in.	8	unc.	1 : .625	60	100	90		Very bright.
	9	10	1 : .625	80	212	112		Do.
	10	unc.	1 : .625	212	212	128		Very bright, continued red in the water 82″, and ebullition ceased in 46″ afterwards.
	11	14	1 : .625	180	212	110		Bright red.
Rolled plate of wr't iron 3-16 in. th'k, 144 oz. wt. 395 sq. in. surface.	12	Quantity of water not observed.	1 : 2.75	60	212	23		Comparable.
	13		1 : 2.75	100	212	23		Do.
	14		1 : 2.75	128	212	33		Full red.
	15		1 : 2.75	175	212	41		Bright red.
	16		1 : 2.75	180	212	25		Comparable.
	17		1 : 2.75	212	212	25		Do.
	18		1 : 2.75	212	212	28		Do.
	19		1 : 2.75	212	212	36		Full red.
Cylinder of wr't iron weighing 16 oz. and comprising a surface of 18.2 square inch.	20	1.375	1 : 1.14	32	133	20	1462	Clear red.
	21	1.375	1 : 1.14	40	127	19	1288	Rather less red, but above comparable.
	22	1.375	1 : 1.14	72	172	21	1449	Clear red.
	23	1.375	1 : 1.14	100	212	25		Do.
	24	1.375	1 : 1.14	112	212	30		Do.
	25	1.375	1 : 1.14	126	212	31		Do.
	26	1.375	1 : 1.14	148	212	36		Do.
	27	1.375	1 : 1.14	168	212	43		Do.
	28	1.375	1 : 1.14	190	212	75		Do.
	29	1.375	1 : 1.14	200	212	77		Do.
	30	1.375	1 : 1.14	212	212	78		Do.

FIFTH SERIES,

With hollow cylinders of copper, presenting 149 square inches of generating surface—water kept at 212°.

No. of experiment.	Weight of metal in ounces avoirdupois.	Time in seconds.	Ounces of steam produced.	Decimal part of an ounce of steam to each ounce of metal.	Ounces of metal to each ounce of steam.	Heat observed.	Remarks.
1	158.50	75	9.875	.0636	16.050	Black.	
2	158.25	50	10.5	.0663	15.071	Black.	
3	157.	70	12.25	.0780	12.816	Reddish by dusk, but not in day light.	
4	159.	70	13.5	.0846	11.777	Do.	
5	159.25	73	14.25	.0895	11.175	*Comparable* dull red.	
6	159.	45	14.25	.0896	11.158	Do.	Immersed at once.
7	158.	55	14.5	.0911	10.896	Do.	
8	156.75	66	14.5	.0925	10.810	Do.	
9	158.75	75	14.75	.0929	10.762	Do.	
10	159.75	75	15.	.0939	10.650	Clear red.	
11	157.5	65	15.25	.0967	10.327	Do.	
12	157.75	70	17.25	.1093	9.145	Bright red.	

The mean amount of metal to the ounce of steam in the five experiments marked *comparable* in the above table, is $10\frac{96}{100}$ ounces, which may be assumed as 11 without sensible error.

SIXTH SERIES,

To determine the quantity of steam yielded by given weights of cast brass at red heat, when plunged into water at 212°.

No. of experiment.	Weight of brass in ounces.	Time in seconds.	Ounces of steam produced.	Weight of steam to an ounce of metal.	Ounces of metal to one ounce of steam.	Heat observed.	Remarks.
1	176	70	15.75	.0895	11.809	Red only in the dark.	Immersed at once.
2	176	120	16.5	.0943	10.666	*Comparable*, (dull red.)	Do. by degrees.
3	175	60	16.75	.0958	10.448	Do.	Do. at once.
4	176	105	17.	.0966	10.353	Do.	Do. more gradually.
5	175	120	17.25	.0985	10.145	Do.	Do. slowly.
6	175	120	17.25	.0985	10.145	Do.	Do. Do.
7	175	180	18.	.1028	9.722	Clear red.	Do. Do.
8	176	75	19.	.1085	9.263	Full red.	Do. at once.
9	176	120	22.	.1250	8.000	Bright red.	Do. gradually.

The five experiments which were made at a dull red heat in day light, and which were therefore marked *comparable*, prove that, on an average, one pound of steam requires $10\frac{35}{100}$ pounds of cast brass of that temperature for its production. It was observed that the violence of agitation, when brass was employed, appeared to be much greater than when similar masses of iron were the subjects of experiment. This was attributed to its higher conducting power. A repetition of this series might not exhibit precisely the same results, unless the specimens employed should have the same proportion of ingredients and the same specific gravity.

SEVENTH SERIES,

With ingots of standard silver, of various weights, from 21½ to 195½ ounces avoirdupois.

No. of experiment.	Weight of silver in ounces avoirdupois.	Time in seconds.	Weight of steam produced.	Parts of steam to one ounce of metal.	Ounces of metal to one ounce of steam.	Heat observed.	Remarks.
1	195.5	120	10.	.0511	19.550	*Comparable,* (dull red.)	Immersed by degrees.
2	26.5	30	1.375	.0519	19.272	Do.	Do. at once.
3	26.5	33	1.5	.0566	17.666	Do.	Do. Do.
4	26.5	30	1.75	.0660	15.143	Clear red.	Do. Do.
5	26.5	32	1.75	.0660	15.143	Do.	Do. more gradually.
6	41.2	50	3.0625	.0740	13.453	Do.	Do. at once.
7	41.2	55	3.125	.0758	13.120	Full red.	Do. Do.
8	195.5	130	15.	.0767	13.033	Do.	Do. gradually.
9	21.5	30	1.75	.0814	12.286	Do.	Do. at once.
10	41.2	68	3.5	.0849	11.771	Do.	Do. gradually.
11	26.5	30	2.5	.0943	10.600	Bright red.	Do. at once; silver beginning to soften.

From a comparison of the three experiments marked *comparable*, in the above table, it appears that about $18\frac{83}{100}$ pounds of standard silver will be required for generating one pound of steam.

EIGHTH SERIES,

With an ingot of pure gold, weighing 14 lbs. $8\frac{1}{4}$ oz. avoirdupois,* and other circumstances as in preceding series, the following results were given.

No. of experiment	Weight of gold in oz. avoirdupois.	Time in seconds.	Weight of steam produced.	Weight of steam to unit of metal.	Ounces of metal to unit of steam.	Heat of metal.	Observations.
1	232.25	100	2 oz.	.0086	116.125	Red in the dark.	The water had remained exposed a short time, and probably lost a few deg's before this exp.
2	232.25	120	5 "	.0215	46.450	Comparable.	Plunged by degrees.
3	232.25	125	6 "	.0258	38.708	Comparable.	Do.

The mean, of the two experiments, made at the temperature of comparison, is $42\frac{55}{100}$ pounds of metal to each pound of steam. The extremely low specific heat of gold, renders necessary every precaution formerly detailed, in regard to avoiding loss of temperature in the water between two successive experiments, and also demands peculiar accuracy and dispatch in the process of weighing. After all the efforts, which were made to insure a correct result, it may have happened that a few degrees of heat, in the gold, were expended in *raising temperature*, and a corresponding deficiency in the quantity of heat *of elasticity* may have been the consequence.

The following summary exhibits a comparative view of the several metals submitted to trial, as shown in the preceding series, indicating the mean result of those experiments in each series which were made at the comparable temperature.

From all the preceding series it appears that at comparable temperature, each pound of steam requires for its production of

Cast iron, - - -	$8\frac{1}{4}$	pounds
Wrought iron, - - -	9	"
Wrought copper, - -	$10\frac{35}{100}$	"
Cast Brass, - - -	$10\frac{96}{100}$	"
Standard silver, - -	$18\frac{83}{100}$	"
Pure gold, - - -	$42\frac{58}{100}$	"

If the temperature assumed for comparison be precisely as much above 212° as is equal to the number of degrees of heat, which be-

* The above mentioned mass of gold, at the mint valuation of $4\frac{1}{25}$ cents per grain, was worth $4105.448. For the use of this, as well as of several ingots of silver, and for other conveniences in these experiments on the precious metals, I am indebted to the politeness of Dr. Moore, superintendent—Mr. Eckfeldt, chief coiner—and other officers of the United States' Mint.

come latent in water while it passes into steam, it is evident that any substance at *comparable* temperature, *and possessing the same specific heat as water*, would generate its own weight of steam in cooling down to 212°. But if its own specific heat be less than that of water, its weight must be proportionally increased, and then the effect of cooling will be the production of the same weight of steam as before supposed. Hence as the *specific heat* is directly proportional to the quantity of *steam* which a given weight of metal would produce, the latter may, at a known temperature, be assumed as a measure of the former. By the following comparison it will be evident that the temperature adopted in these experiments *was* nearly identical with that which I have above alluded to, and which exceeds 212°, by the amount of latent heat (990°) in a unit, by weight, of steam.

	Steam to the unit of metal.	Specific heat.	
Iron,	.1111	.1100	Petit & Dulong.
Copper,	.0907	.0949	" "
Brass,	.0940	.1100	Dalton.
Silver,	.0532	.0557	Petit & Dulong.
Gold,	.0236	.0298	" "

It must be observed that the above statements of specific heats, taken from Petit and Dulong, are those of the mean effect from 0° to 100° centigrade. That of silver, for example, is .0557 within these limits, but if the mean specific heat found by them from 0° to 300° cent. be adopted, it will come somewhat above the result of my experiments, that is .0611.

The method which has thus been adopted, adds another to the means heretofore employed for determining the specific heat of many solid and gaseous substances, or at least of verifying the results of former methods. The three modes, just alluded to, are those of *mixture*, of *melting ice*, and of *cooling in air*, the last in particular seems liable to many objections on account of the different conducting and radiating power of the bodies, and the different natures of the surface which may be given to each, whereby the *time* of cooling, which is made the measure, will be exceedingly variable.

The calorimeter, of Lavoisier, is not regarded as correct in its indications, on account of the subsequent congelation of a portion of the ice, melted by the hot body, and the rise of temperature in water by *mixture*, involves the necessity of considering the increase of temperature, in the containing vessel, together with its separate

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specific heat, before any accurate result can be anticipated. The method of generating steam from an apparatus kept at a uniform temperature, and by means of bodies of known *superior temperatures*, is, I conceive, less liable to objection from any of these sources of fallacy. The only modifying cause, which deserves much attention, is the *barometric pressure* during the experiment, which involves also a consideration of the specific heat of steam under different pressures, but as this source of error may be obviated by performing experiments at uniform pressures, we need hardly take it into view, in estimating the general correctness of the mode now proposed of verifying the specific heats of bodies.

By knowing at what temperature we plunge a piece of metal under boiling water, the weight of the metal, and its mean capacity for heat, we may readily infer, from what is known of the quantity of latent heat in the unit by weight of steam, what weight of the liquid will be boiled off while the metal is reduced from a superior temperature down to 212°.

Thus let the *temperature* of the metal above 212° $=t$

Its *weight* $=w$

Its mean *capacity* between 212° and the known temperature $=c$

The latent *heat* of atmospheric steam $=l$

The weight of *steam* which the metal can produce $=s$

Then will $s=\frac{tcw}{l}$. Thus, suppose $t=2000°$, $c=.1111$, $w=16$oz. and $l=990°$, then we shall have $\frac{tcw}{l}=\frac{2000\times.1111\times16}{990}=3{,}571$ ounces.

From the above formula we derive immediately an expression for the *temperature* when all the other elements are known; for $ls=tcw$, whence $t=\frac{ls}{cw}$; so that when we would determine the actual temperature of a body above 212°, whose specific caloric has been carefully ascertained, we have only to *find what weight of vapor it will produce in coming down to the point of ebullition; multiply this by the latent heat in steam, and divide the product by the product of the weight of heated matter multiplied by its specific heat.* Upon the basis of this proposition I have constructed an instrument called the *steam pyrometer*, to be applied to the measurement of heat in incandescent metals, coals and furnaces, to mark the melting point of metals, to verify the results presented by other instruments employed in similar operations, and to answer some other practical and scientific purposes.

The several series of experiments heretofore detailed, in relation to the actual *quantity* of vapor yielded by red hot metal, and to the *time* employed in producing it, have furnished some of the data for calculating the effect of overheating a steam boiler and immediately furnishing it with water. It is evident, that even with the same temperature in the metal, certain circumstances may exist at one time which shall modify the result exhibited at another. The tenth experiment in the fourth series,* in which 60 ounces of metal continued red for 82 seconds, beneath the surface of boiling water, and afterwards occupied 46 seconds in parting with the excess of heat above 212° which then remained, might possibly lead to the inference, that the quantity of heat disengaged in the former part of the operation was at least twice as great as that which was given out in the latter. This would imply that the temperature, (omitting difference in specific heat,) had been at first three times as much above 212°, as it was at the moment when redness disappeared. But the whole of the fourth series, as well indeed as all the other series heretofore given, had manifested in the performance of the experiments, a much more vigorous action subsequent to the disappearance of redness, than before that period. It was therefore necessary, in order to obtain some degree of clearness on this head, to perform several *courses*, each consisting of a number of *series* of experiments.

The general fact that red hot metal repels water, or at least does not appear to exercise upon it any *contiguous* attraction, has long been familiar. The smith who plunges a piece of iron, at a white heat, into his trough, sometimes sees with astonishment that scarcely any agitation of the liquid occurs for the first few seconds; and he perceives that this is not due to the coldness of the water, requiring it to be heated up to boiling temperature, before it can undergo the agitation consequent upon the formation of steam; for by plunging another piece of metal at a black heat into the same liquid, the action becomes immediately and distinctly perceptible.

When water is sprinkled upon a stone plate, even below redness, the drops are often observed to roll, apparently with little or no adhesion, from side to side, until slowly dissipated, or until they at length become attached and finally disappear, amidst a rapid ebullition and a violent hissing noise.

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* See Vol. XX, p. 311, of this Journal.

In the use of his generators, somtimes at the temperature of redness, Mr. Perkins had occasion to notice the fact above described, and to observe that the repulsion, between the metal and the water, sometimes becomes intense, amounting to a force greater than that of the elasticity of the steam, and that a small pipe heated red hot, might become entirely choked up, so to speak, with caloric, and incapable of transmitting any water or steam.

It may also be mentioned, that Klaproth has performed some experiments on a small scale, illustrative of one part of the subject now under consideration. But they seem to have given rise to some erroneous deductions in regard to the action of metal. It appears to have been inferred, that, as in cooling his *spoon* down from a white to a black heat, he passed from the time of 40″ to 0″ in the evaporation of six drops,—he had actually arrived at a point where the action of metal upon water would be *instantaneous*.

From his experiments, and those of Perkins, it has likewise been inferred that the point of *incandescence* is that from which the repulsion of water from the surface of metal commences; and that above redness, the augmentation of temperature is always attended by a corresponding diminution in the rapidity of evaporation. An opportunity will perhaps be embraced in a future paper to recur to these opinions.

The mode of performing the first of the following courses of experiments, was by procuring a basin of wrought iron about eight inches broad, one inch and three fourths deep at the center, and one fourth of an inch thick, made from a piece of rolled iron, and weighing three pounds and a half. This was heated, either over a spirit lamp, with an argand burner, in a stove of anthracite, capable of maintaining a heat near whiteness, or at a forge fire, urged by a powerful bellows. When deemed sufficiently hot, it was withdrawn from the fire, and care being taken that no dust or ashes adhered to the surface, a measured portion of water was laid upon the center, the time from the moment it struck the metal till the last drop disappeared being carefully noted from an accurate time keeper, and recorded by an assistant. The temperature of the water was marked by a good thermometer, or was kept boiling by remaining constantly over the fire during a whole series. The trials were continued as long as the metal remained hot enough to produce vapor of atmospheric elasticity. The proceeding has rendered it highly probable, that the rate of cooling after the period of most rapid action has been attained, varies considerably from that which precedes, and

that possibly different stages of rapidity will be discovered, in different parts of the series following the time of most rapid vaporization.

First course, *comprising twelve series.*

Exhibiting the times in which given quantities of water of known temperature, may be successively converted into vapor, while the iron which produces it is cooled from redness to the point of ebullition.

No. of exp. in each series.	1st series, 1.7-8 oz. water at 194° Fahr.	2d do. 1-2 oz. do. 200° do. 8 experiments.	3d do. 1-4 oz. do. 178° do. 11 experiments.	4th do. 1-8 oz. do. 190° do. 13 experiments.	5th do. 1-8 oz. do. 188° do. 14 experiments.	6th do. 1-8 oz. do. 185° do. 14 experiments.	7th do. 1 8 oz. do. 190° do. 15 experiments.	8th do. 1-8 oz. do. 178° do. 17 experiments.	9th do. 1-8 oz. do. 188° do. 17 experiments.	10th do. 1-8 oz. do. 182° do. 18 experiments.	11th do. 1-16 oz. do. 175° do. 25 experiments.	12th do. 1-16 oz. do. 188° do. 29 experiments.
	″	″	″	″	″	″	″	″	″	″	″	″
1	50	105	93	173	126	134	121	66	111	78	66	80
2	55	25	23	19	14	15	16	18	13	12.5	17	37
3	176	15	12	9	9	6.5	7.5	9	9	5.5	7.5	14.5
4	.	21	14	14	11.5	10	9	9	9	7.5	7	9
5	.	31	19	17	14.5	14.5	12	11	10	9	6	6.5
6	.	41	25	22	17	16	15	14	11.5	11	5.5	6
7	.	69	30	24	19.5	19.5	16.5	15	15	14	5.5	5.5
8	.	150	43	28	21.75	20	19	19	17	14.5	5	6.5
9	.	.	57	37	26	27	22	20	19	17	5	7
10	.	.	67	50	31	30	26.5	22	23	19	5.5	8
11	.	.	135	63.5	38	38	30	25	27	22	5.75	8
12	.	.	.	99	49	49	39.5	31	30	24	6	8.5
13	.	.	.	174	70	66	54	38	41.5	25	7	9.5
14	.	.	.	.	89	99	72	45	50.5	33	7.5	11
15	.	.	.	.	.	.	107	68	72	40	8	11.5
16	.	.	.	.	.	.	.	95	93	50	13	13
17	.	.	.	.	.	.	.	190	183	82	18	14
18	.	.	.	.	.	.	.	.	.	135	20	15
19	.	.	.	.	.	.	.	.	.	.	22	15.5
20	.	.	.	.	.	.	.	.	.	.	25	17
21	.	.	.	.	.	.	.	.	.	.	34	19
22	.	.	.	.	.	.	.	.	.	.	42	22
23	.	.	.	.	.	.	.	.	.	.	50	26
24	.	.	.	.	.	.	.	.	.	.	83	30
25	.	.	.	.	.	.	.	.	.	.	140	36
26	.	.	.	.	.	.	.	.	.	.	.	44
27	.	.	.	.	.	.	.	.	.	.	.	59
28	.	.	.	.	.	.	.	.	.	.	.	89
29	.	.	.	.	.	.	.	.	.	.	.	156.5

RESULTS.

1st series. $5\frac{5}{8}$ oz. generated in	281″	2d series. 4 oz. generated in	457″
2 intervals, 60″ each	120	7 intervals 10″ each	70
whole time of the series,	401	whole time of the series	527

3d series. $2\frac{3}{4}$ oz. generated in 518″
10 intervals, 6.5″ each 65

whole time of the series 583

4th ser. $1\frac{5}{8}$ oz. generated in 727.5″
12 intervals, 6.8″ each 82.5

whole time of the series 810

5th ser. $1\frac{3}{4}$ oz. generated in 536″
13 intervals, 12.9″ each 169

whole time of the series 705

6th ser. $1\frac{3}{4}$ oz. generated in 534.5″
13 intervals, 10.8″ each 140.5

whole time of the series 675

7th ser. $1\frac{7}{8}$ oz. generated in 567″
14 intervals, 10″ each 140

whole time of the series 707

8th series. $2\frac{1}{8}$ oz. generated in 695″
16 intervals, 6″ each 96

whole time of the series 791

9th ser. $2\frac{1}{8}$ oz. generated in 724″
16 intervals, 11″ each 176

whole time of the series 900

10th ser. $2\frac{1}{4}$ oz. generated in 598.5″
17 intervals, 16″ each 271.5

whole time of the series 870

11th ser. $1\frac{9}{16}$ oz. generated in 613″
24 intervals, 7″ each 168

whole time of the series 781

12th ser. $1\frac{13}{16}$ oz. gener'd in 780.5″
28 intervals, 8.2″ each 230.5

whole time of the series 1011

As the water covered generally but a small part of the surface of the basin even at the commencement of the experiment, the heat in the latter terms of each series, must have been furnished to the water more slowly than in the preceding terms, both on account of the diminution of difference between the metal and the liquid, and on account of the necessity of depending on the conducting power of the metal, to bring the heat from the exterior to the center of the basin. Hence we might expect to find the terms obeying some law of geometrical progression. If we examine the last seven or eight experiments in each series, we shall clearly perceive such a progression. Omitting the last of each column, as presenting anomalies obviously derived from the final disappearance of vaporization, and the substitution of mere *evaporation*, we may divide the last number but one, by that which precedes it; this latter, by the next preceding, and so on, until we obtain five quotients. These quotients will constitute the ratios of the series, at the particular points where the experiments took place. The mean results for each series may then be obtained in the usual mode. But it will soon be perceived that if we extend the divisions beyond five or six, the ratio will be essentially varied in its character, and the series, in some instances, becomes

almost exactly coincident with an arithmetical progression. Thus the 12th series, from the 11th to the 20th experiment, inclusive, may be regarded as composed of the numbers 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, while from the 23rd to the 28th, we have 26, 30, 36, 44, 59, 89, yielding the ratios $\frac{30}{26}=1.153$, $\frac{36}{30}=1.200$, $\frac{44}{36}=1.222$, $\frac{59}{44}=1.341$, and $\frac{89}{59}=1.508$, and the mean of all these ratios is 1.285.

By similar operations applied to the concluding part of every series in this course except the first and second, we obtain the following mean ratios for the several series respectively, viz.

for	the	3rd	series	1.290
"	"	4th	"	1.334
"	"	5th	"	1.276
"	"	6th	"	1.302
"	"	7th	"	1.270
"	"	8th	"	1.308
"	"	9th	"	1.285
"	"	10th	"	1.292
"	"	11th	"	1.316
"	"	12th	"	1.285

If we would know the mean of all their mean ratios, we have but to divide their sum by 10, the number of series considered, whence we obtain 1.296 for the general ratio of this part of the several series. It will, however be remarked that the five ratios belonging to the 11th series are themselves in geometrical progression, whose mean ratio is 1.07.

In order to present to the eye the whole range of experiments in some of the series, I have adopted the method of curvilinear projection, assuming as the unit of vapor, the amount actually employed at each trial, and as the unit of time, the number of seconds taken to vaporize it, at the period of most rapid action. Representing these units by equal vertical and horizontal lines respectively, the relative time of action in each experiment marked on the line *a c*, is denoted by the dotted lines, *a d*, *c g*, &c. Figs. 1, 2 and 3. Regarding *ab* as a constant quantity, we have the portions of time above the *minimum*, represented by that part of each vertical which is above the tangent *b f*. It will be seen by Fig. 1. that the arithmetical series exists in the 6th, 7th, and 8th experiments. Fig. 2d. shows the same feature at the 17th 18th, and 19th, while the 12th series, represented by Fig. 3, shows a straight line from No. 11, to No. 20, as already stated. See the plate at p. 71.

The next course of experiments was performed on a more extended scale, by using a cylinder of cast iron about seven inches long, and three inches in diameter; having at one end a cylindrical hole nine tenths of an inch in diameter, and three and three quarters of an inch in depth, concentric with the axis of the cylinder, and of course penetrating below the centre of the mass. The weight of the cylinder was about ten pounds. This cylinder, heated to redness, was placed on the solid base, and the water was deposited from a suitable measuring tube, in the hole at the upper end, due care being taken to clear the interior surface of scales and dust at the moment it was withdrawn from the fire. In this course, the red heat was maintained for a much longer period than was practicable with the rolled plate, when withdrawn from the fire. The time when redness disappeared, was generally noted, and is marked *b* against the number of seconds registered, at the experiment where it occurred. The *minimum* time is indicated in like manner by *m*.

SECOND COURSE, *containing nine series.*

To exhibit the rate of decrease, the time of most violent action, and the subsequent increase of time of vaporization in a cylinder of cast iron, employing an equal quantity of water at each trial in the same series.

Order of succession in the experiments of each series.	1st. series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness.	7th series. 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water at 212°, kept briskly boiling Iron white.
1	31″	26.5″	27″	14″	14.5″	18″	20″	27.5″	17″
2	30	26	27	13	14	16	20	28	17
3	30	26	24	12	14	16	19	34	15
4	30	26	23	11.5	14	16	18	39	15
5	31	26	23	10.5	14	15.5	17.5	30	14.5
6	34	25	20	10.5	13	15	17	33	14.5
7	30	24	20	10.5	12	14.5	17	22	14.5
8	33	24	19	10	11	14	17	20	13
9	34	22	17	10	11	13	17	18	13
10	29	21	15	10	12	12	16	17	12
11	27.5	19	13	10	11	12	15	17	11.5

TABLE CONTINUED.

Order of succession in the experiments of each series.	1st series, 1·8 oz. of water, at 65°, at each exp. Iron red hot when taken from the fire.	2d series, 1·8 oz. of water, at 80°. Iron very bright red.	3d series, 1·4 oz. of water, at 212°. Iron near whiteness.	4th series, 1·8 oz. of water, at 190°. Iron bright red.	5th series, 1·8 oz. of water, at 190. Iron bright red.	6th series, 1·8 oz. of water, at 200°. Iron near whiteness.	7th series, 1·8 oz. of water, at 200°. Iron nearly white.	8th series, 1·16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1·16 oz. of water, at 212°, kept briskly boiling. Iron white.
12	27.5″	18.5″	13″	9.5″	11″	11″	14.5″	16″	11.5″
13	30	18	12	9.5	11	11	14	16	11
14	31	18.5	12	9	11	11	14	16	12
15	29	18	12	9	10	11	13	16	12
16	29	18.5	12	9	10	11	13	16	12
17	25	18	11	8.5	10	10.5	12	15	12
18	21	18	10	8	10	10.5	12	15	12
19	20*b*.	17.5	10*b*	8	10	10	12	15	11
20	20	17.5	10	8	10	10	11	14.5	11
21	20	17*b*	10	8.5	10	10	10	14.5	11
22	20	17	10	8	9.5	10	10	13	10
23	19	17	10	8	9.5	10	9.5	12	10
24	19	17	10	7.5	9.5	10	9.5	12	10.5
25	21	17	8.5	7	10	10	9.5	11	10
26	21	16.5	8.5	7	9.5	10	9.5	10.5	9
27	22	16.5	8	7	9.5	9.5	9	10	8.5
28	20	17	8	7	8	9.5	9	10	9
29	23	16.5	8	6.5*m*	8	9	8.5*b*	10	9
30	17	16.5	8	7*b*	8	9*b*	8	9	8.5
31	20	16	7	8	7*b*	9	7.5	9	8.5
32	18	16	7	8	6*m*	8.5	7	9	8.5
33	18	16	7	8	6	8	7	8.5	8
34	17	16.5	7	7.5	8	8	6.5	8.5	8
35	17	16.5	7	7.5	7	8	7	8	8
36	16.5	16	6.5	8	7	8	8	8	8
37	16	16	7	7.5	7	8	7	7	8
38	15	15	6.5	7	7	8.5	7	7*b*	8
39	15	14	7	8	7	8.5	7	7	7
40	15	14	6.5	7.5	8	7	6.5	7	7
41	14.5	14	7	7.5	8	7	6.5	7	7
42	18	14	6*m*	7.5	7	7	6	7	6.5*b*
43	16.5	14	7	7.5	7	7	6	6.5	7
44	15	14	7	8	7	7	6	6.5	7
45	16	14	7	7.5	8	7	6	6	7
46	15	14.5	6.5	7.5	8	6.5	6.5	6	6.5
47	15	14.5	7	8	8	6*m*	6.5	6	6.5
48	15	14	6.5	8	9	6.5	6.5	6	6.5
49	13*m*	14	7	8.5	9	7	6	6	6.5
50	13	13*m*	7	9	9	7	6	5.5	6.5
51	13	13	6.5	9	9	7	6	5.5	6.5

TABLE CONTINUED.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
52	13″	14″	6.5″	9.5″	9″	7″	5*m*.	5*m*.	6″
53	13	14	7	10	9.5	7	6	5	6
54	16	14	8	11	9.5	7	6	6	6
55	21	15	8	12	10	7	6	5	6
56	22	15	9	12.5	11	7	6	6	5
57	23	18	10	12.5	10.5	8	7	5	6
58	26.5	19	10	14	12	8	6	5	5.5
59	47	22.5	12	14	11	8	6	5	5.5
60	210	25	15	14	12	8	6.5	5	5
61	.	43	19	15	13	8	6.5	5	6
62	.	188	24	16.5	14	8	7	5	6
63	.	.	27	18	14	8	7	5	6
64	.	.	36	19	14	7.5	7	5	5
65	.	.	40	21	15	7.5	7	6	5.5
66	.	.	55	23.5	16	8	7	5.5	5
67	.	.	80	28	17	8	7	6	5
68	.	.	137	31.5	20	9	8	6	6
69	.	.	.	33	20	10	8	6	5.5
70	.	.	.	39	22	10	8	6	5
71	.	.	.	56	22	10	9	6	5
72	.	.	.	64	23	10	9.5	6	5
73	.	.	.	179	24	10	10	6	5
74	.	.	.	.	25	10.5	10	6.5	5
75	.	.	.	.	28	10.5	10	6.5	4.5*m*.
76	.	.	.	.	37	11	10	6	5
77	.	.	.	.	46	12	10	6	4.5
78	.	.	.	.	54	13	10	6	6
79	.	.	.	.	88	13	10.5	6	5
80	.	.	.	.	154	14	10.5	5.5	5
81	.	.	.	.	.	15	11	5.5	5.5
82	.	.	.	.	.	15	13	5.5	5
83	.	.	.	.	.	18	14	5.5	5
84	.	.	.	.	.	19	14.5	5.5	5
85	.	.	.	.	.	20.5	17.5	6	5
86	.	.	.	.	.	24	18	5.5	5
87	.	.	.	.	.	25.5	19	6	5
88	.	.	.	.	.	33	21	6	5
89	.	.	.	.	.	44	23	6	4.5
90	.	.	.	.	.	56	26	6.5	5
91	.	.	.	.	.	92	29	6	5

TABLE CONTINUED.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
92	.	.	.	.	.	296″	38″	6″	4.5″
93	.	.	.	.	.	.	60	6	4.5
94	.	.	.	.	.	.	163	6	4.5
95	.	.	.	.	.	.	.	6	5
96	.	.	.	.	.	.	.	6	6
97	.	.	.	.	.	.	.	6.5	5
98	.	.	.	.	.	.	.	6.5	5.5
99	.	.	.	.	.	.	.	6.5	5
100	.	.	.	.	.	.	.	6.5	6
101	.	.	.	.	.	.	.	6.5	5
102	.	.	.	.	.	.	.	7	5.5
103	.	.	.	.	.	.	.	7	5
104	.	.	.	.	.	.	.	7	5.5
105	.	.	.	.	.	.	.	7	6
106	.	.	.	.	.	.	.	7	5.5
107	.	.	.	.	.	.	.	7	6
108	.	.	.	.	.	.	.	7	6
109	.	.	.	.	.	.	.	7	5.5
110	.	.	.	.	.	.	.	7	6
111	.	.	.	.	.	.	.	7	5.5
112	.	.	.	.	.	.	.	7	6
113	.	.	.	.	.	.	.	7	5.5
114	.	.	.	.	.	.	.	7	5.5
115	.	.	.	.	.	.	.	7	5.5
116	.	.	.	.	.	.	.	7	5
117	.	.	.	.	.	.	.	7	6
118	.	.	.	.	.	.	.	6.5	5.5
119	.	.	.	.	.	.	.	6.5	5.5
120	.	.	.	.	.	.	.	7	5.5
121	.	.	.	.	.	.	.	6	6
122	.	.	.	.	.	.	.	6	6
123	.	.	.	.	.	.	.	6.5	7
124	.	.	.	.	.	.	.	6	6
125	.	.	.	.	.	.	.	6	6.5
126	.	.	.	.	.	.	.	6.5	6.5
127	.	.	.	.	.	.	.	7	6.5
128	.	.	.	.	.	.	.	6.5	7
129	.	.	.	.	.	.	.	7	7
130	.	.	.	.	.	.	.	6	7
131	.	.	.	.	.	.	.	6	6.5
132	.	.	.	.	.	.	.	6	6.5

TABLE CONTINUED.

Order of succession in the experiments of each series.	1st series, 1-8 oz. of water, at 65° at each exp. Iron red hot when taken from the fire.	2d series, 1-8 oz. of water, at 80°. Iron very bright red.	3d series, 1-4 oz. of water, at 212°. Iron near whiteness.	4th series, 1-8 oz. of water, at 190°. Iron bright red.	5th series, 1-8 oz. of water, at 190°. Iron bright red.	6th series, 1-8 oz. of water, at 200°. Iron near whiteness.	7th series, 1-8 oz. of water, at 200°. Iron nearly white.	8th series, 1-16 oz. of water, at 212°, kept in rapid ebullition during the whole series. Iron white.	9th series, 1-16 oz. of water, at 212°, kept briskly boiling. Iron white.
133	.	.	.	.	.	.	.	7"	6"
134	.	.	.	.	.	.	.	7	6
135	.	.	.	.	.	.	.	7	6
136	.	.	.	.	.	.	.	7	5.5
137	.	.	.	.	.	.	.	7	6
138	.	.	.	.	.	.	.	7.5	6
139	.	.	.	.	.	.	.	7.5	6
140	.	.	.	.	.	.	.	7.5	6
141	.	.	.	.	.	.	.	7.5	5
142	.	.	.	.	.	.	.	8	5.5
143	.	.	.	.	.	.	.	8.5	5.5
144	.	.	.	.	.	.	.	9	5
145	.	.	.	.	.	.	.	9	5
146	.	.	.	.	.	.	.	10	5
147	.	.	.	.	.	.	.	10.5	5
148	.	.	.	.	.	.	.	12	5
149	.	.	.	.	.	.	.	12	6
150	.	.	.	.	.	.	.	12	5.5
151	.	.	.	.	.	.	.	13.5	5
152	.	.	.	.	.	.	.	15	5
153	.	.	.	.	.	.	.	15.5	6
154	.	.	.	.	.	.	.	18	6
155	.	.	.	.	.	.	.	20	6
156	.	.	.	.	.	.	.	22	6
157	.	.	.	.	.	.	.	29	6
158	.	.	.	.	.	.	.	32	7
159	.	.	.	.	.	.	.	33	6
160	.	.	.	.	.	.	.	37	7
161	.	.	.	.	.	.	.	58	6.5
162	.	.	.	.	.	.	.	88	7.5
163	.	.	.	.	.	.	.	154	8
164	.	.	.	.	.	.	.	.	10
165	.	.	.	.	.	.	.	.	11
166	.	.	.	.	.	.	.	.	14
167	.	.	.	.	.	.	.	.	15.5
168	.	.	.	.	.	.	.	.	20
169	.	.	.	.	.	.	.	.	25
170	.	.	.	.	.	.	.	.	32
171	.	.	.	.	.	.	.	.	47
172	.	.	.	.	.	.	.	.	69
173	.	.	.	.	.	.	.	.	134

RESULTS.

1st *Series.*—Vaporized $\frac{60}{8}$ oz. of water in 2100″—viz.
water was on the metal 1497″
59 intervals 10.2″ each 603″
Black at No. 19.—Minimum, No. 49.

2d *Series.*—Gave $\frac{62}{8}$ oz. of vapor in 1800″—viz.
water remained on 1292.5″
61 intervals 8.32″ each 507.5″
Black at No. 21.—Minimum, No. 50.

3d *Series.*—Gave $\frac{68}{4}$ oz. of vapor in 1800″—viz.
water was on 1065.5″
67 intervals 10.9″ each 734.5″
Black at No. 19.—Minimum, No. 42.

4th *Series.*—Gave $\frac{73}{8}$ oz. of vapor in 1920″—viz.
water was on 1092″
72 intervals 11.5″ each 828″
Black at No. 30.—Minimum, No. 29. (Surface oxidized.)

5th *Series.*—Gave $\frac{80}{8}$ oz. of vapor in 2100″—viz.
water was on 1244.5″
79 intervals 10.8″ each 855.5″
Black at No. 31.—Minimum, No. 32. (Oxide.)

6th *Series.*—Gave $\frac{92}{8}$ oz. of vapor in 2100″—viz.
water was on 1420″
91 intervals 7.47″ each 680″
Black at No. 30.—Minimum, No. 47.

7th *Series.*—$\frac{94}{8}$ oz. of vapor in 2162″—viz.
water was on 1232″
93 intervals 10″ each 930″
Black at No. 29.—Minimum, No. 52.

8th *Series.*—Gave $\frac{163}{16}$ oz. of vapor in 2700″—viz.
water was on 1819″
162 intervals 5.44″ each 881″
Black at No. 38.—Minimum No. 52.

9th *Series.*—Gave $\frac{173}{16}$ oz. of vapor in 2700″—viz.
water was on 1510″
172 intervals 6.91″ each 1190″
Black at No. 42.—Minimum, No. 75.

The eighth series in the second course, is represented in projection by the curve, (Fig. 4.) of the accompanying plate. The reader will remark that the linear unit, assumed to represent the minimum time and its corresponding quantity of vapor, is one tenth of an inch in this figure, whereas it is two tenths in those which relate to the first course.

In addition to the results of the fourth and fifth series, where the most rapid action occurred almost simultaneously with the cessation

of redness, numerous other facts had convinced me that the approach to this period is greatly accelerated by the adhesion of any non-conducting substance to the surface of the iron. Indeed, it often appeared sufficient for the water to find and seize upon a mere point of such material as a nucleus, to enable the fluid speedily to reduce the temperature of the surrounding surface. By detaching a scale of oxide, around which the effect just described had begun to take place, I have sometimes succeeded in arresting the progress of vaporization, and by giving the liquid once more a clean red surface, even with the scale floating loosely in the water, to establish once more the slow evaporation which belongs to that state of the metal.

To ascertain what effect the incrustation generally formed upon the interior of a steam boiler might be expected to produce, in augmenting the rapidity of action in a case of overheating, I performed the following course of nine series, employing for that purpose, the basin used in the first course, commencing with its surface clean, and having tried the effect of pure water at 212°, subsequently poured in a portion of cold water, into a pint of which about two ounces of clayey garden earth had been put, producing a degree of turbidness as great probably as any of our rivers possess in the time of freshets. The iron was kept constantly over a brisk fire, and, in some of the series, was permitted to come to bright redness before each experiment; while in others, the operation commenced with redness, but was continued in so immediate a succession, as to reduce the metal to a certain point of constant action; but never attaining the *most rapid* period.

It will be perceived that the first series was made in pairs, alternately—two with clean water at the boiling point and two with the muddy water above mentioned. The other series were made with similar alternations of single experiments, with the exception that both hot and cold water were free from impurities when laid upon the metal. The ratios placed among the results of this course, will prove that on an average, water at 212° laid upon hot metal under the circumstances described, requires 15½ per cent. longer for its evaporation than a like quantity of water at 60°. This result, which appears at first rather startling and paradoxical, is readily explained when we consider the efficacy of cold water in bringing the coating and even the surface of the metal down towards the temperature of most rapid action,—a point, at which the mere difference of temperature becomes an insignificant element in the calculation, compared with the vastly augmented speed with which the vapor is then generated.

THIRD COURSE, *embracing nine series.*

To exhibit the effect of incrustations in augmenting the action of hot metal, during the first stages of vaporization from its surface, and also to show the relative efficacy of hot and cold water in this particular.

Order of experiments in each series.	1st *Series.*—Iron red—evaporated 1-8 oz. of water at each experiment, gradually coating the surface with clay.		2d *Series.*—Commenced with iron red—1-8 oz. alternately clear and muddy water.		3d *Series.*—Begun by evaporating 2 oz. of muddy water, forming a crust on the metal, on which put 1-8 oz. each time.		4th *Series.*—1-8 oz. laid on crust of clay, in immediate succession.		5th *Series.*—1-4 oz. of water used each time, begun at bright red and brought down to a temperature of constant action.		6th *Series.*—1-4 oz.—iron red hot before each experiment.		7th *Series.*—Begun by adding a third oz. of muddy water to the crust already formed. This evaporated in 45″—1-4 oz. each time—iron full red at every trial.		8th *Series.*—Added a 4th oz. of muddy water—took 35′—then iron red each time—hot and cold water applied—1-4 oz. at each experiment.		9th *Series.*—On the coat of clay from 4 oz. of muddy water, put 1 oz. of clean water at 60°, in immediate succession.
	Water, 212° (clean.)	Do. 60° (muddy.)	Do. 212° (clean.)	Do. 60° (muddy.)	Do. 212° (clean.)	Do. 60° do.	Do. 212° do.	Do. 60° do.	Do. 212° do.	Do. 60° do.	Do. 212° do.	Do. 60° do.	Do. 212° do.	Do. 60° do.	Do. 212° do.	Do. 60° do.	
	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″	″
1	95	.	23	.	14	.	13.5	.	21	.	30.5	.	21.5	.	15	.	30
2	100	.	.	21.5	.	12	.	10.5	.	18	.	26	.	19	.	14.5	26
3	.	72	20	.	14	.	13	.	18	.	28	.	24	.	18	.	25
4	.	52	.	20	.	13.5	.	11	.	15	.	26	.	21	.	15.5	24
5	53	.	20	.	15	.	12	.	14.5	.	30.5	.	24.5	.	.	.	25
6	50	.	.	20	.	13	.	10.5	.	14	.	25	.	20	.	.	24.5
7	.	45	19	.	15.5	.	12	.	13.5	.	35	.	22.5	.	.	.	25
8	.	31	.	18	.	13.75	.	10.5	.	12	.	25	.	20	.	.	25
9	26	.	17	.	17.5	.	.	.	13	.	39	.	24	.	.	.	.
10	24	.	.	17	.	14	.	.	.	13	.	29	.	21.5	.	.	.
11	.	26	16.5	.	17.5	.	.	.	13	.	.	.	24	.	.	.	.
12	.	27	.	16	.	14	.	.	.	11.5	.	.	.	21.5	.	.	.
13	19	.	15.5	.	.	.	.	.	13	.	.	.	24.5	.	.	.	.
14	23	.	.	15	.	.	.	.	.	11.5	.	.	.	21	.	.	.
15	.	22	13.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16	.	21	.	14.5	.	.	.	.	.	.	.	.	.	.	.	.	.
17	19	.	13.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18	18	.	.	13.5	.	.	.	.	.	.	.	.	.	.	.	.	.
19	.	.	13.5	.	.	.	.	.	.	.	.	.	.	.	.	.	.
20	.	.	.	13.5	.	.	.	.	.	.	.	.	.	.	.	.	.
21	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

RESULTS.

1st *series.*—Time reduced from 100′′ to 18″ by the coat of earthy matter successively deposited from $\frac{3}{8}$ths oz. of muddy water.

2d *series.*—Hot water constant at 13.5″
Cold water do. do.

3d *series.*—Mean time for hot water 15.6″—coated metal red hot, each time.
Mean time for cold water 13.37″.
Ratio of cold to hot 1 : 1.167.

4th *series.*—Hot water constant at 12″.
Cold water constant at 10.5″.
Ratio of cold to hot 1 : 1.143.

5th *series.*—Hot water constant at 13″.
Cold water constant at 11.5″.
Ratio of cold to hot 1 : 1.130.

6th *series.*—Mean time for hot water 32.6″.
Mean for cold water 26.2″.
Ratio of cold to hot 1 : 1.244.

7th *series.*—Mean for hot water 23.6″.
Mean for cold water 20.6″.
Ratio of cold to hot 1 : 1.145.

8th *series.*—Mean for hot water 16.5″.
Mean for cold water 15″.
Ratio of cold to hot 1 : 1.100.

9th *series.*—Constant at 25″ to the ounce.

The first series represents the gradual diminution of time from 100 " down to 18" and shows that here the impurity suspended in the water, retarded vaporization more than the depression of temperature could accelerate it. In the second series, the two effects became exactly counter-balanced and so remained through several experiments more than are given in the table.

FOURTH COURSE, *consisting of six series.*

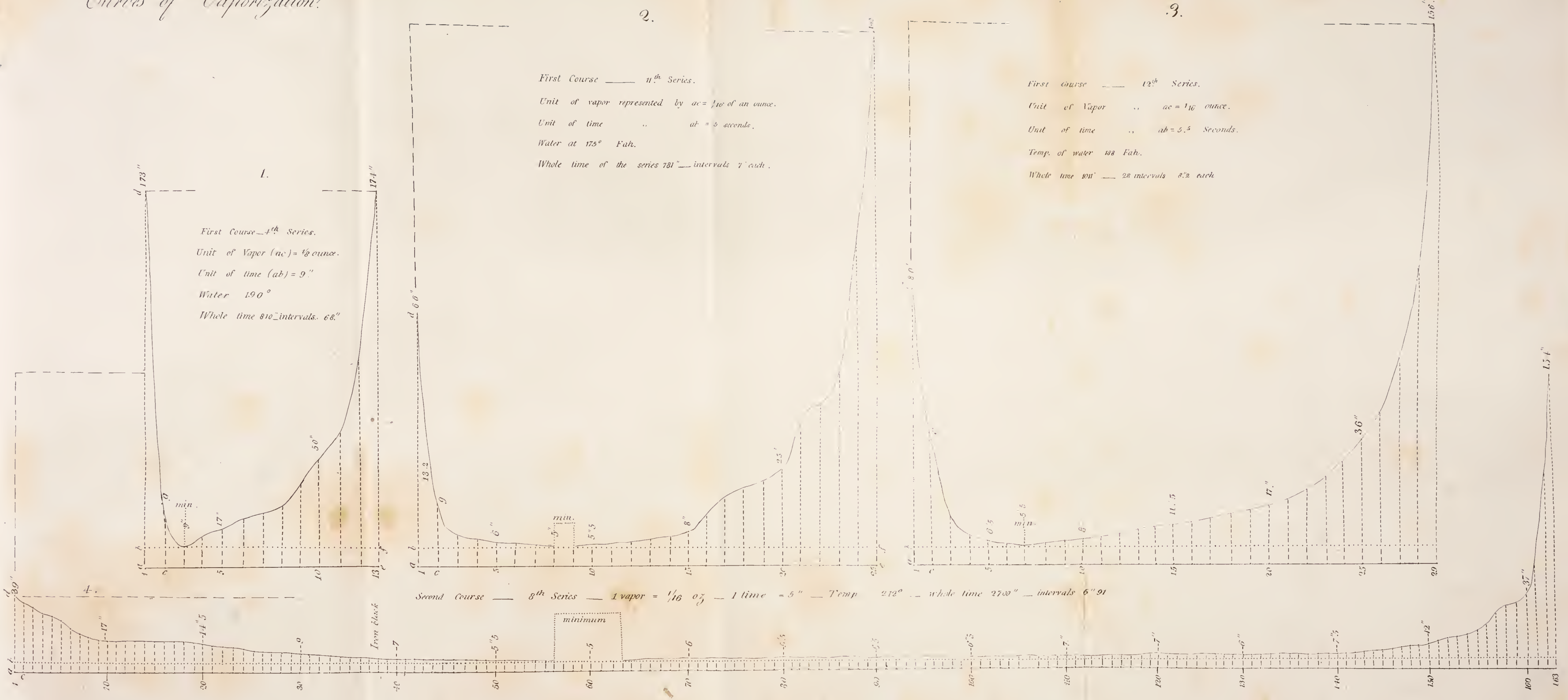
The sixth being intended to show the times required to evaporate, or to vaporize equal portions of water from the surface of iron when placed cold upon a vivid coal fire, with the delays necessary to raise the temperature up to the point of most rapid action and thence to the state in which the water ceases to moisten the surface ;—the other series being designed to exhibit the relation in time, between hot

and cold water upon a clean surface, varying the correspondent portions of each from $\frac{1}{8}$oz. to 2oz. at each experiment.

Order of experiments.	1st *Series.*—1·8 oz. at each experiment—hot and cold water alternately.		2d *Series.*—1·4 oz. at each experiment—hot and cold water alternately.		3d. *Series.*—1·2 oz. at each experiment—hot and cold water alternately.		4th *Series.*—1 oz at each experiment—hot and cold water alternately.		5th *Series.*—2 oz. at each experiment—hot and cold water alternately.		6th *Series.*—1·8 oz. put on the iron cold, and same quantity in immediate succession.	
	Water 212°.	Do. 60°.	Water 212°.	Do. 60°.	Water 212°.	Do. 60°.	Water 212°.	Do. 60°.	Water 212°.	Do. 60°.		Water 60°.
	″	″	″	″	″	″	″	″	″	″		″
1	104		108		150		182		266			40
2		68		93		137		158		220		16
3	96		102		150							9
4		64		84		126					ceased 60″	9
5	100											8
6		94									ceased 30″	8
7	90											6.5
8		79										6
9	95										ceased 60″	6
10		74									black	64
11	90										visibly red	60
12		80										75
13	80										clear red	73
14		74									"	80
Mean.	93.5	76	105	88.5	150	131.5	182	158	226	220	constant 80″	
Ratio.	1.23 : 1		1.186 : 1		1.14 : 1		1.151 : 1		1.209 : 1			

The mean of all these ratios is 1.183 which shows that with a clean surface the limited quantity of hot water requires $18\frac{3}{10}$ per cent. longer to effect its vaporization from the red hot metal than an equal quantity of water at 60° ; so that though the times are vastly different in this course from what were given in the last, the relation is nearly the same, being only 3 per cent. more favorable to the cold water, than when the surface was incrusted with earthy matter. Accidental circumstances sometimes vary or even invert the relative times for hot and cold water, but such discrepancies are easily referred to their proper causes. The limits of this paper compel the postponement of several courses of experiments.

Curves of Vaporization.



EXPERIMENTAL INQUIRIES, &c.

The developement of the law of action between a heated surface and water of different temperatures, has been, in part, presented by preceding courses of experiments.

To persons conversant with this subject it will readily occur, that the facts and principles connected with vaporization are highly important to the arts, independently of their relation to the steam engine. The numerous processes of manufactures, in which liquids are to be reduced by boiling, are often performed in a manner totally at variance with philosophy, as well as with economy. The manufacture of salt by vaporization, for example, is an extensive and increasing branch of our national industry, and is generally carried on with very little attention to the saving of fuel, by any of those devices and arrangements which the practical science of the present age might suggest.

The chief points proposed to be examined at present, are—

1. The *temperature of most rapid vaporization* under atmospheric pressure.

2. The nature of the phenomena exhibited at that point, as well as immediately above and below it.

3. Effects of lubricating the surface of the metal, of covering the surface of the water with a thin fibrous texture, and of thickening it with a farinaceous substance.

4. The influence of mechanical pressure in bringing the liquid in contact with the metal and accelerating the vaporization.

5. The action of hot metal on other liquids, particularly alcohol.

6. Some opinions which have gained currency in regard to the temperature of repulsion, and the degree of rapidity with which heat may be imparted to liquids, will likewise require attention.

1. To ascertain the temperature at which the most rapid action takes place, two methods have been employed. The *first* was by using a basin of wrought iron, having at the bottom a small quantity of mercury, into which the bulb of a thermometer was plunged. Upon the surface of the iron, near the mercury, small measured portions of water were successively deposited, while the basin was placed over an argand spirit lamp. These portions were not of sufficient amount or frequency to prevent the increase of temperature in

the metal, and consequently the times of vaporization were diminished to a certain point, after which they were observed to increase. The temperature had then reached the point where repulsion begins. The temperature at the moment when the point of repulsion appeared to have been attained was noted, and the experiments continued until an unequivocal increase in the time of evaporating the unit of water was observed. The lamp being now withdrawn, the temperature was allowed to descend, and the rapidity of vaporization was of course augmented; still lowering the temperature, the point of greatest action was passed, and the production of steam became slower from want of sufficient heat.

By thus reversing the temperatures, and alternately passing and repassing the point of most vigorous action, the limits of that action were determined to a certain degree of exactness. It soon became evident, that it was far below the boiling point of mercury, and considerably above that of water boiling in open air. It was not difficult to ascertain too, that the range of most rapid action lay between 300° and 350°. In order to vary the mode of experimenting, and, at the same time, to give more exact indications in several particulars, the *second* method, above referred to, was devised. This consisted in employing a bar of iron, about 14 inches long, $1\frac{7}{10}$ wide, and $1\frac{1}{10}$ thick. A number of cylindrical holes, half an inch in diameter, and one inch apart, (from centre to centre,) were bored along one of the sides, extending nearly through the thickness of the bar. Adjacent to each of these holes, which were five in number, were sunk small conical cavities, $\frac{3}{10}$ of an inch deep and $\frac{7}{10}$ of an inch in diameter at top, forming basins or *cups* to receive drops or other small measured portions of liquids. The cylindrical holes were to receive mercury, into which the bulbs of thermometers could be plunged, to ascertain the temperature of the part of the bar and of the cup opposite. The thermometers were supported from above, by hooks bent over the bar and placed in proper positions to allow the bulbs to descend just far enough to be completely immersed in the reservoir of mercury, but not to carry the centre of the bulb below the level of the bottom of the contiguous cup.

By this means the temperature of the mercury was measured, at a point where it must have been the same as that of the generating surface. The five receptacles of mercury were placed near the middle part of the bar, leaving a part four and a half or five inches long at each end, without holes; but the line of cups already mentioned was extended in both directions, nearly to the extremities of

the bar. By this means the nature and mode of action could be observed, at points above that of mercurial ebullition.

Heat was applied at one end of the bar, either by means of a spirit lamp, or by thrusting the end into an opening through the side of a furnace. As the temperature rose, the cups near the end next the fire, were, of course, first brought to a vaporizing temperature; then the cup opposite to the nearest mercurial reservoir and the others in succession, with greater or less rapidity according to the tension of the heat at its source. It was generally found most advantageous to employ, for a source of heat, the convenient chemical spirit lamp with argand burner, which has been devised by Dr. J. K. Mitchell. When the temperature was sufficiently raised, drops of water were simultaneously projected into two or more of the cups, and by the inequality in the times of final disappearance, their relative influence was easily perceptible. This mode of operating, by allowing the temperature to be gradually raised admitted of a succession of five series of trials, one for each cup, so that when the time of vaporization, in one, had begun to *increase*, that is, when the time of most rapid action in that cup had been passed, and the action had become slow through excess of heat, it was only necessary to commence with the next cup, more remote from the source of heat. The period of greatest rapidity was now perceived to lie between 304° and 320°. The range of temperature through which the most rapid action existed was hence limited between two points, equally remote from 312°, or from 100° above the boiling point of water.

2. The nature of the effect here observed resembled that of vigorous attraction. This necessarily creates a constant struggle between the vapor which is quitting, and the liquid which is approaching any given point of the metallic surface. On brass, the action appeared more vigorous, and the temperature of repulsion higher than in the case of iron. On mercury, at 500°, a drop of water was, on one occasion, found to remain seventy seconds; but at 340° a drop of this metal formed a good nucleus, about which the water when repelled by a surface of iron, at the same temperature, would gather, and thence obtain heat to vaporize itself, while portions not in contact with the mercury would lie upon the iron almost quiescent.

At temperatures considerably below that of most rapid vaporization, there was constantly exhibited, in the various series of experiments, a decided tendency in the water to adhere to the metallic surface, and when by contact with a given portion of surface, and by receiving and rendering latent in vapor, the heat which the latter had

possessed, the temperature of that portion was somewhat reduced, the stratum of water was observed to glide away to other, hotter parts of the surface, even against the force of gravity.

This effect was observable in the cylinders with which the *second course* on *variable rapidity*, was performed. Towards the conclusion of each series, the water, after ceasing to boil in the bottom of the cylindrical cavity, ascended in many instances quite to the top of the cylinder, and even spread outward on all sides wherever it met with a higher temperature than 212°.

The same phenomenon was noticed in the basin already described, and in the bar above mentioned. To make this effect the more distinct, a broad shallow pan of extremely thin iron, commonly called by the tin plate workers, "black tin," was procured. In the centre of this, a slight elevation, about one tenth of an inch high, was made, with a corresponding cavity on the under side, or bottom of the pan.

A lamp being applied beneath the elevated part, the iron soon obtained a dull red heat in the dark. Water was then laid upon the basin so as to surround completely the centre, and form a sort of island of heated surface. As the heat extended by degrees, and reached the line of water, the latter was observed to start upwards from its line, and moisten a portion of the surface not before wetted.

By agitating the water with a hair pencil, and creating a wave towards the centre, the *line of vaporization* became distinct. By raising the waves still higher, that of repulsion was manifest, and by causing a surge high enough to break quite over the insulated elevation, the alternate attractions and repulsions were seen in the drops and masses which, having been driven forcibly beyond the first line of vaporization, or that which they encountered on their ascent, were subsequently rolled quite over the centre of the elevated embossment, but arrested with great promptitude as they rolled down and reached the line of vaporization on the opposite side.

3. In order to ascertain the influence of certain lubrications in reducing the rapidity, I placed the bar over a spirit lamp in such a manner as to bring two of the mercurial reservoirs, and their adjacent cups at equal distances from the centre of flame. Having allowed the temperature to reach 300°, I applied equal portions of water to each cup, and found their actions precisely alike. I then placed and spread, as lightly as possible, a minute portion of olive oil, forming a thin film over the surface of one of the cups, allowing the other to remain clean. On renewing the applications of water, it was found that the oiled took four times as long as the clean surface to vaporize

a certain quantity of water. On elevating the temperature, the oil itself was gradually evaporated, and the water found occasional admittance to the surface. Hence the difference was gradually diminished, and the wonted action of the iron restored, but the addition of fresh portions of oil, again reduced temporarily the vaporization on the surface to which it was applied. But as the temperature was more elevated than before, the oil likewise became sooner dissipated.

By exposing the bar in a similar manner, and ascertaining that two contiguous cups, equally remote from the centre of flame, were, when both clean, precisely alike in regard to the rapidity of evaporation at a high temperature, I lubricated one with plumbago, laid on by rubbing a piece of that substance over the interior, without however leaving any dust or small bits of the mineral to serve as *nuclei* for the water to seize upon. The other cup was left clean as before. Equal portions of water at 60° were now laid simultaneously upon the bottom of the two cups. The mean result, of six experiments in each, was that the cup with plumbago required eighty four seconds to evaporate its liquid, while the cup without plumbago took but forty one for that purpose. The portions of liquid used were single drops for the respective experiments.

To ascertain the effect of thickening the water into a thin paste, I put a large tea-spoon full of flour into an ounce of water, and laid one-fourth of an ounce of the mixture on the bottom of the iron basin, kept red hot over the fire. The evaporation took place, and the paste became dry in seventy-eight seconds. Under precisely the same circumstances, clear water, of the same temperature as that mixed with the flour, required one hundred and thirty-eight seconds to evaporate one-fourth of an ounce.

The action on clear water was rendered much more rapid, however, by covering the surface with a circle of white paper laid on immediately after the water was put into the basin. The evaporation then took place in seventy-two seconds. In another experiment, in which the circle of paper was smaller than that of water, the time was increased to ninety seconds. In both of these cases, the acceleration appeared to proceed, in part, from the obstruction which the paper opposed to the rotation of the circle of water. When a very small circle of paper, or any other light body, was placed upon the surface, it soon acquired the motion of the fluid, and the exceeding velocity of the latter became manifest to the eye. The rotary motion is not however the uniform result of such experiments.

There will often be seen a scalloped figure with a greater or less number of re-entering curves, destroyed and reproduced with astonishing rapidity and regularity. A slight humming noise was also occasionally perceived, as the liquid was alternately raised and depressed by this species of movement. Gravity was here put in equilibrium with the repulsive force of caloric, and as the equilibrium must from the nature of the fluid be *unstable*, there was a constant effort of those parts of the fluid which happened for a time to be less resisted than others by the heat, to obey gravity and come nearer the surface; but as they descended they came to be, in turn, more vigorously resisted, and sent up again with energy, even beyond the distance of equilibrium. A new descent was the consequence, and the alternation once established, was easily maintained by the momentum of the fluid and the perfect elasticity of the spring on which it constantly impinged. This phenomenon is similar in character, and probably admits a similar explanation to that of an experiment of Mr. Faraday, in which a segment of a cylinder of metal has a narrow groove cut longitudinally along the convex side, forming two *straight edges* one or two tenths of an inch asunder. If this segment, heated to four or five hundred degrees, is laid on another polished metallic plane surface, so as to rest upon the two edges, it will soon acquire a rapid oscillatory motion, bringing the two edges alternately in contact with the plane below. This oscillation may be sufficiently rapid to cause a ringing or humming noise. In this case the radiation is from the oscillating body *downwards*, while in that of a fluid undergoing evaporation, it is from the fixed plane to the oscillating body or liquid *upwards*.

The temperature of the liquid while resting over the red hot surface of iron, was found to be 210°.

4. The resistance to actual contact, which is furnished by heat in both the cases just mentioned, is exemplified in many processes of art. The attempt to perforate a bar of hot iron with a cold steel *bit*, will present a sensible illustration of this point. The resistance may however, by mechanical pressure, be overcome to such an extent as to bring the solid in one case, and the liquid in the other, into such contiguity, as to restore in some degree the adhesion of the liquid or the abrading power of the steel. The pressure may be applied directly to the liquid when placed upon a metallic plate, by means of another smooth metallic surface pressed immediately upon the drop of liquid. Smart vigorous explosions may be thus produced, similar to the well known cracking under a smith's hammer which has been dipped in

water and then applied to a hot bar of iron, or to the overheated face of an anvil.

The pressure of an elastic gas or vapor may, in like manner, be employed to urge the liquid into contact with the metal; and, it is evident, must become at every instant the more effectual, both as the pressure is increased by the accumulating mass of steam, and as the temperature is diminished towards the point of most rapid action. It will be understood that the calculation formerly made respecting the power which an overheated boiler of given dimensions could produce, was intended only to exhibit the *amount of atmospheric steam.*

5. It becomes interesting to inquire whether any other liquid than water is affected, in a similar manner, by the overheated metallic surface. The trial soon convinced me that in regard to alcohol, at least, the same general phenomena take place. It may at first appear singular, that a given portion of this liquid, (the boiling point of which is at 174° Fahr.) should require for its evaporation a longer time when laid upon a plate of iron at 400° or 500° than when poured into the hand of the experimenter, the temperature of which is not above 98°. Such however appears to be the fact. When one sixteenth of an ounce of alcohol was laid upon the centre of an iron basin, heated to at least 500°, the time of its final disappearance was one hundred and forty five seconds; while an equal quantity of the same spirit required but ninety seconds to evaporate it from the palm of the hand. It is true, that in the latter case, the extent of surface occupied by the spirit was unavoidably greater than that on the iron. The liquid was diffused by capillary attraction, or perhaps by its attraction for heat, over the whole surface of the palm, notwithstanding the efforts to confine it to a single spot. At a temperature when the iron became barely red in the dark, the time of disappearance was from one hundred and ten to one hundred and twenty seconds.

The next thing was to determine the time requisite to vaporize one sixteenth of an ounce of alcohol, *when the metal was at a temperature to give a maximum energy of action* between it and the spirit. By several trials for this purpose, it was found to be three and a half seconds. The *greatest length of time* during which the same quantity had been found to remain was one hundred and fifty seconds. Whence it appears, that the relation between the two is $\frac{3.5}{150}=\frac{7}{300}$, or $\frac{1}{43}$ nearly. The only remaining question was the actual temperature at which the spirit disappeared in the least time. For this pur-

pose, recourse was had to the bar with mercurial reservoirs and cups, already described. On raising the temperature to 312°, where water had been observed to be most rapidly vaporized, it was manifest that the alcohol was clearly and strongly repelled.

The temperature was then lowered to 280°, when occasional signs of adhesion were manifested, and a corresponding diminution in the time of evaporating a given quantity of liquid was the result.

By lowering the temperature of the iron to 260°, the time was again perceived to increase on account of a *deficiency* of heat. By thus passing and repassing several times between 260° and 280°, the limits of range became circumscribed between 270° and 278°, and finally the point of most vigorous action seemed to rest at 274°, the arithmetical mean of the above mentioned limits. This, it will be recollected, is 100° above the boiling point of alcohol. It will be observed also, that this is exactly as much above its boiling point, as the temperature of most activity on water is above the boiling point of that liquid.

6. An allusion has already been made to the opinion of some writers, that the repulsion of a liquid from metal begins at the temperature of incandescence, and increases as the temperature rises. The facts already detailed in this paper, will serve to show that the former opinion is wholly without foundation. Indeed, when we reflect for a moment on the nature and cause of that diminution of the liquid which takes place after *vaporization has ceased through an excess of temperature*, we must perceive that as the effect is an *evaporation*, due to the radiation of heat, the rapidity with which the latter will disperse a given quantity of water must be proportionate to the *tension* of the heat at the radiating source; that is, the surface of the metal. Evaporation must commence where vaporization ceases, and the former must be slow when the tension is barely sufficient to elevate the liquid out of the sphere of contact, or of contiguous attraction. This cannot however prevent an increase of rapidity, when the tension at the source is sufficiently elevated to allow the radiated heat to communicate temperature to a *transparent medium*.

To place the matter beyond a doubt, the iron basin already mentioned was used. When exposed to the white heat of a forge fire, a given weight (one eighth of an ounce) of water was evaporated in sixty seconds. At the bright red heat of an anthracite stove, eighty seconds were required to produce the same effect. When exposed on an open grate of anthracite, in such a manner as to maintain the

centre only of the basin at a very faint red heat in the dark, the time was extended to three hundred and fifteen seconds.

Another comparison, made upon portions of water of one sixteenth of an ounce each, gave the following results. On the metal, at the bright red heat of the stove, the water lay sixty six seconds; on the centre of the basin dull red, as before, in the dark, it continued one hundred and eighty three seconds; while over a spirit lamp, the metal being constantly black and the temperature probably not above 600°, it remained two hundred and eighty six seconds.

In all the above experiments, the heat was constantly supplied, and the temperature may be regarded as having been uniform during each trial. Hence, the opinion that repulsion increases with the temperature, appears not to be sustained. When the temperature has decidedly surpassed the point where contiguous attraction can take place, every elevation of temperature is attended with a corresponding diminution of time required for evaporation.

In order to illustrate more fully this branch of the subject, a series of experiments was made with the iron basin, placed over a coal fire and supplied with doses of one sixteenth of an ounce of alcohol, sp. gr. .854, (32.5° Baumé.) The first experiment was made at a temperature about 400° to 500°.

The following was the succession.

Exp. 1	142″	Exp. 3	140″
2	145	4	117

The temperature of the metal continued to rise notwithstanding the application of the successive portions of spirit, and as the time for each experiment was obviously decreasing through an *excess of temperature*, the basin was removed from the fire and allowed to stand for some time, until it was cooled below the point of *minimum activity*. It was then again placed upon the fire, and when the fifth portion of liquid was placed upon it, exhibited symptoms of a slight tendency to attract the latter. The sixth experiment was made after sufficient time had elapsed again to permit a rise of temperature.

Exp. 5	87″	Rapidity increased by deficiency of temperature to maintain the repulsion uninterrupted.
6	150	Iron kept some time on the fire without liquid before this experiment.
7	143	
8	134	
9	123	

Exp.	10	120″	Very faintly luminous in the dark.
	11	115	Redness gradually increased.
	13	113	
	14	100	
	15	95	
	16	82	

The surface of the basin about the spirits exhibited when the room was darkened, a very distinct luminousness, like a faint lambent flame, owing, probably, to the vapor being heated nearly to redness at the moment of production. A similar appearance had been observed in the vapor of water, produced from metal at a white heat.

Having now removed the basin from the fire, the experiments were continued, and the time was observed to increase from eighty two seconds to one hundred and five, and then to one hundred and thirty five, after which it began to diminish, as the establishment of cohesion between the liquid and the metal became more decided, thus

Exp.	17	105″	Exp.	20	17″
	18	135		21	10
	19	90			

The above series of experiments is in accordance with several of those made upon water, where the initial temperature of the iron was very great and the mass sufficient to supply heat of a high tension, to the evaporating surface, for a considerable length of time after being removed from the fire. This was the case in the *first*, *second*, *fifth* and *eighth* series in the *second course* on the rate of decrease.* In those cases, the times exhibited either a succession of numbers nearly equal, or an actual increase during the first five or six experiments of each series. This is particularly remarkable in the eighth series, of which a projection has been given. The order of magnitudes, for the first six experiments, beginning with the highest, was followed in that projection, merely for the purpose of exhibiting the extremes of retardation, both by excess and by deficiency of temperature, in the production of vapor. The reader will perceive however that the actual order of occurrence of these six experiments which began at a *white heat* and lasted, including intervals, 218.7 seconds, was 27.5, 28, 44, 39, 30, 33. It needs hardly be stated, that the idea of *instantaneous* action between iron and water, derives no confirmation from any of the foregoing series of experiments.

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* See page 24.

Description of an instrument called the Steam Pyrometer.

A careful attention to guard the containing vessel in which we produce steam from boiling water by means of metal, or other solid or liquid bodies capable of being heated in open vessels above 212° Fah. will enable us to measure with great accuracy, the quantity of heat which such solid or liquid body expends in cooling, from the temperature at which it is first put in, down to the boiling point of water.

The mode of calculating the temperature when the specific heat is known, has already been given. The only points of much difficulty in rendering the formula heretofore stated, directly useful in pyrometry are, 1, the necessity of defending the vessel in which the steam is produced, from the effects of radiation and conduction during the operation; 2, the obviating of loss in transferring the hot body to the liquid through the air; 3, the means of obtaining and marking the true boiling point, and 4, the means of speedily and accurately weighing the liquid, and showing how much has been evaporated during an experiment.

To these causes of inconvenience, may be added, that which results from the low specific heats of some of the substances, to be employed as standards.—Such are several of the metals as platina, gold, &c. It is obvious that the method of plunging the body of which we would know the temperature directly into boiling water, can be adopted only with regard to solids, which remain unchanged after being quenched in water, and which are not capable of imbibing the fluid, on account of porousness, or such physical characters as would render them liable to combine chemically with the water.

When we have to deal with liquids of which the temperatures extend beyond that of boiling mercury, that is, of mercury boiling in vacuo, (which must necessarily limit our use of the mercurial thermometer,) we must either pour such liquid into the boiling water, if a melted metal which will not undergo change in that method of cooling, or must enclose it in a suitable vessel extremely thin and of materials to sustain the action of water upon it, or must immerse in the hot liquid or the melted metal, a mass of some other matter capable of preserving its form under a heat greater than that of the liquid. The latter method is on several accounts to be preferred. First we may always use the

same amount of hot matter to produce the vapor, and consequently compare the actual heats of two melted masses without calculation. Second, the hot body may be directly applied to the water without the intervention of any enclosing vessel. Third, the pouring of the hot metal or liquid into water might not always be convenient or safe, as for example when the latter is of greater specific gravity than the former. When, for example, oil is laid at a very high temperature, on the surface of water, the sudden ebullition of the water, would be in danger of causing an explosion that would project the oil upwards with great force.

When we plunge a solid into a melting mass of metal, and allow it to remain for some time, it will acquire the temperature of the mass of melted matter, but the *solid* must have certain peculiar properties to fit it for this purpose.

First, it must not melt at a lower point than that of the fluid which it is intended to test.

Second, it must allow of being quenched in boiling water from the highest temperatures employed, without cracking, scaling, oxidizing, or undergoing any augmentation of weight by absorbing the liquid.

Third, it must have as high a *specific heat* as practicable.

Fourth, it should be capable of being easily wrought into the peculiar form required for the instrument with which it is to be used.

Among the substances best adapted for the purpose are the following, against each of which the specific heat is marked together with the name of the author, whose determination has been followed.

	Spe. Heat.	Authorities,
Crown glass,	.2000	Irvine,
White glass,	.1870	Wilcke. (.1770, Pet. and Dul.)
White clay, burnt,	.1850	Gadolin.
Black lead or plumbago,	.1830	Do.
White cast iron,	.1320	Do.
Soft bar iron, sp. gr. 7.724,	.1190	Do.
Platinum,	.0314	Petit and Dulong.

The chief parts of this instrument are a boiler, A; (Fig. 1.)—a stand, S;—a balance beam, D, for weighing the boiler and its contents;—a lamp, L, to heat the water and to maintain ebullition between experiments;—a receiver, R, (Figs. 2 and 3.) and a cylinder of metal, I, to be employed as a *standard.*

The boiler is formed of two concentric cylinders of copper. The inner cylinder is two and a half inches in diameter, the exterior one is four inches, leaving a space of three fourths of an inch to be filled with finely powdered charcoal or lampblack, seen at O, in the section (Fig. 2.)

The *interior* cylinder rises half an inch above the exterior, which is twelve inches high. The former is then expanded into a funnel-shaped mouth, F, five inches in diameter at top, and two inches perpendicular height, intended to receive and return any portions of water which might be thrown up by ebullition, but not converted into steam. From the lower part of the apparatus a third concentric cylinder, K, rises about three inches and one fourth, where it terminates in a conical head furnished with a pipe, P, passing obliquely upwards through the two cylinders before mentioned, and firmly soldered to both. The purpose of this third cylinder is to receive the lamp L, and to expose a large surface to the action of its flame. *e* is a stopper intended to close the pipe, P, when the lamp is withdrawn and the experiment in progress. E is an index attached to the support *m*, in such a manner that the point E, may be elevated or depressed a few degrees, to correspond to the position of the beam D, and save the adjustment by weights *before* an experiment. The cylinder of lead C, is movable along the rod by means of a screw thread, cut the whole length of that arm. This mode of adjustment admits of the greatest accuracy, and is liable to less delay than the sliding weight. By means of the tightening screw *t*, the support *m m*, may be placed at any convenient height on the rod *r*, and by means of *s*, the lamp L, may be loosened and caused to revolve horizontally when the metal is about to be immersed; in which case the boiler will be for the time depressed, and will rest on the cushion B, which is composed of hare's fur, covered with soft flannel to defend the bottom from the access of air; the stopper *e*, is a further safeguard against the same source of loss. A thermometer *g*, bent at right angles, passes through the two concentric cylinders, having the bulb directly exposed to the water within, but defended from injury by a projection of its tube *o*, a short distance beyond the inner cylinder.

The receiver R, is about four inches in height, and one and a quarter in interior diameter, furnished above with a tube *l*, and a stop cock *k*, to convey away the steam, and to carry it, when required, into a vessel of cold water. The only direct access of the water *x*, to the hot

body I, when in place, is through the *bottom* of the receiver. If the stop cock be closed the steam will soon fill all the surrounding space and keep the water down quite to the lower edge, but if the cock be opened, the steam finding an outlet will rise, and the water will follow and again produce a large quantity of vapor. It will generally be found expedient to allow a moderate discharge only at the mouth of the pipe, and to cause the greater part of the action to take place through the metal of the receiver R. The only uses indeed of this part of the apparatus are 1st, to receive, without loss of heat, the standard piece I, and deposit it in the water without coming in contact with the exterior air, and 2d, to prevent the dispersion of the water by the extreme rapidity of its action, particularly towards the close of the operation. The pipe of R, is wrapped with flannel.

The manner of transferring the standard-piece is seen in Fig. 3, where G is a cylindrical or slightly conical recipient either entirely closed, or having a few orifices *h*, *h*, *h*, at the bottom. This recipient is to be formed either of iron, copper, silver, platina, plumbago, wedgewood ware, or crucible clay, according to the heat to which it is to be exposed, or the materials into which it is to be plunged. It will often be found expedient to protect the cylinder I, from the direct action of the fused metal, of which we would ascertain the temperature, otherwise there might be an adhesion of some portions of the melted mass which would vitiate the experiment. When the body I, has been heated to the requisite degree, and is to be transferred to the receiver R, the container G, is laid, by means of the handle, *q*, *u*, on some convenient support; R is then inserted at the mouth so that the hook *p*, shall be on the same side with the handle; G and R are then inclined so that I may slide from the bottom of G into R, the latter is then rolled over upon the side *p*, when the concave base of I, will be received upon the hook, and the cylinder will take the position indicated by the dotted figure, the moment R is raised to a vertical position.

It may then be plunged in an instant into the boiling water, as seen in Fig. 2. The quantity of vapor produced, is shown by the weights W, *w*, which it may be necessary to add to A in order to restore the position of the beam, so that the index E, shall again point to an engraved line on the side of the bar.

The receiver R, may be kept in the water when not required for immediate use, and be weighed with the liquid both before and after

the experiment. By this means its temperature will be the same as that of the water, and no calculation necessary.

The lamp L, instead of being removed by revolving to allow the generator A, to rest on the cushion B, may rise through the center of that cushion, which may, in turn, be supported by the rod attached at *s*. This arrangement is seen at B, Fig. 2, where the rod Q, sustains a small circular platform and cushion, as well as the lamp L. The advantage of this arrangement is the saving of time, and the only inconvenience, that the lamp must be relighted after each experiment, as it will be extinguished by closing P and preventing the access of air from below to K. It must obviously not be kept burning under the generator during the experiment.

Instead of employing weights as at W, *w*, to reproduce the counterpoise, or show the equivalent weight of steam produced, I have graduated one *end* or *base* of the counterpoise C, by radiant lines, and caused to be removed a segment of about 60° along the screw D, through its whole length, so as to present a vertical plane surface, on which to form a scale; the graduations of this scale are, of course, regulated by the distance apart of the threads of the screw; the weight of the counterpoise is such that one revolution on the thread produces a difference of one hundredth of a pound at the boiler end of the beam. The periphery of C is then graduated into one hundred equal divisions, (indicated by the figures 0, 1, 2, 3, &c.) so that, as a complete revolution of the counterpoise, towards the end of the rod, marks an increase of one hundredth of a pound in the weight of water put into A, so a corresponding movement in the reverse direction, compensates for the same amount of loss by evaporation; and a movement through one of the *centigrade* divisions only, or one hundredth of a revolution, as marked on the end of the cylinder, of course indicates one hundredth of the above amount, namely one ten thousandth of a pound. If greater exactness were required, it might be obtained either by making the threads at a less distance apart, or by diminishing the counterpoise C, and substituting for a part of its weight a fixed weight M.

I have found the apparatus sensible to the fourteen thousandth of a pound or half of a grain, when fully charged for use, that is, when the boiler contained at least sixteen ounces of water.

The arrangement above indicated may be varied to suit the different purposes to which the instrument may be applied, and the stand-

ards will be different according to the temperatures to which they must be exposed. If the substance, of which the temperature is to be ascertained, can with safety be plunged beneath the surface of boiling water, without causing either chemical change or variation of specific gravity, this direct action of the substance is doubtless to be preferred to the intervention of any second substance as a standard. The quantity, or number of *therms** of heat present, in a given weight of the substance in question, will then be known, and if we know or can determine the specific heat, we may calculate the temperature as already indicated. I have, in this manner, proved the quantity of heat present in melted iron. Practical men may, possibly, from occasionally experiencing the tremendous effect of generating a quantity of steam from the moisture of their moulds, imagine that the experiment of pouring melted iron into a vessel of boiling water will be attended with danger. But I can assure them, from repeated trials, that it is perfectly safe. Plunge into a bucket of water, a common small iron kettle, supported on feet: pour into this, when completely immersed, any convenient quantity of melted iron; the ebullition from the surface of the melted mass will be at first very slow or scarcely perceptible, while from the outside of the kettle it will be very vigorous. The whole will subsequently exhibit the same effects as are perceived when a piece of cast iron is immersed at a bright red heat.

The following experiment was made in August, 1831. Twelve ounces of melted iron were poured into about six pounds of water, at 212°: the result was eight ounces of steam produced. In order to calculate this case, and obtain the actual *power present in the state of heat* at the time of the immersion, we have to multiply the weight of steam by its latent heat, say 990°, which gives 7920°; this divided by the weight of metal, (twelve ounces,) gives 660 for the number of ounces of water, which one ounce of the metal would have heated one degree, in cooling itself down to 212°. But as the *temperature* of the metal is the thing required, we must divide the above by the specific heat of cast iron, say $\frac{1}{8.25}$ or .1212, which gives $660 \div .1212 = 5445°$. But it will be recollected, that a portion of this must be regarded as the *latent heat of melted iron.*

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* See Ch. Dupin. Méchanique, tome 3. p. 353, et seqq.

In order to show what the latent heat of cast iron *is*, we may adopt the plan of taking from a mass of melting iron, a lump not actually liquefied, quench it, and observe the weight of steam produced. Again, pour from the same mass a portion of the liquefied metal, and ascertain how much *more* steam, for the same weight, is given by the latter than by the former. The same proceeding may be adopted for all other metals and their alloys.

The following experiments and calculations will show the mode of applying the steam pyrometer.

1. A cylinder of cast iron, weighing 5668 grs., was heated to redness. It was then placed within the receiver and instantly plunged into boiling water, previously accurately weighed; after the entire cessation of ebullition, it was withdrawn and the deficiency supplied by weights. The heat had been a moderately red heat;—now, as cast iron has a specific heat of about .1212, this multiplied by 5668 will give the equivalent weight of water $=687$, which heated to the same degree might produce the same effect. In the case just stated, the quantity of water found to have been evaporated was 674. Hence 674 multiplied by the latent heat in steam, ($=990°$ Fahr.) gives $667260° =$ the grains of water which would be heated one degree by condensing the steam now generated. But as the iron was equivalent to only 687 grains of water, it must have been heated as many degrees above 212°, as 687 is contained times in 667260°, which is 971.2 times; hence this number added to 212° will give the temperature of the iron, expressed in degrees of Fahrenheit's scale, equal to 1183.2.

2. Another experiment, conducted in the same manner, and with the same cylinder, but at a cherry red heat, gave 945 grains of steam. By applying to this case the principle of the formula, as before, we have, as above, $5668 \times .1212 = 687$, for the equivalent of the iron in weight of water; and $945 \times 990 = 935550 =$ the grains of water which would be heated one degree by the condensation of the steam produced. Then $935550 \div 687 = 1362 =$ the number of degrees which the iron must have lost in producing this effect, while it came down from its initial temperature of redness to 212°. To this again we add 212°, and obtain 1574° for the actual temperature.

3. A ball of cast iron, weighing 1665 grs., was heated to a bright red, and gave 230.2 grains of steam. Here $1665 \times .1212 = 201.8$ $=$ the equivalent weight of water, which, if heated to the same tem-

perature, would have produced the same effect, viz. $230.2 \times 990 = 227898$. Now this divided by 201.8 gives $1128 =$ the degrees above boiling point, at which the temperature was at first, or $1128 + 212$ is equal to the actual temperature abore the zero of F., viz. 1340°.

4. With the same ball, a second experiment gave 139 grains of steam. Hence $990 \times 139 = 137610$, and this divided by $201.8 = 681.8$, and to this add 212 and we have 893.8 for the temperature at first.

5. The next experiment was with a cylinder of wrought iron, weighing 6110 grains, having a specific heat of .1100, and consequently being equivalent to $6110 \times .11 = 672$ grains of water. The observed heat was a moderate red, and the loss in weight of water 780 grains, whence the temperature must have been $(780 \times 990) \div 672 = 1149 + 212 = 1361°$ Fah.

6. The same cylinder was again employed, and raised to a bright red, so as to "scale" on exposure to the air. It then gave 989.6 grains of vapor; consequently its heat must have been $\frac{989.6 \times 990}{672} = 1462°$ above the boiling point, or 1674° of Fahrenheit's scale.

The process of calculation may be much simplified, when the specific heat of the *standard piece* has been accurately ascertained and its equivalent of water found; for we have then only to multiply the weight of steam produced by its latent heat, or heat of elasticity, and divide by that equivalent. This is the same as multiplying the *weight of steam* by a known constant fraction. In the fifth experiment above cited, the equivalent of the metal is 672 grains of water, so that the constant fraction by which to multiply the weight of steam actually generated, in any given experiment with that cylinder of iron, in order to obtain the temperature above 212°, is $\frac{990}{672} = \frac{165}{112}$, or (in decimals) 1.4732. This number, multiplied by 780, gives the degrees 1149, as before. The process may be farther abridged, by performing the multiplication by logarithms, in which case we should have the logarithm of 1.4732 constant, and hence it would only be necessary to find in the table the logarithm of the grains of steam, add it to said constant quantity, and find the *number* standing against their *sum*, for the temperature above 212°.

Thus, the logarithm of 1.4732 is	.168259
To which add the logarithm of 780 =	2.892095
And we obtain the logarithm of 1149° =	3.060354

STEAM PYROMETER BY W. R. Johnson.

Fig. 1.

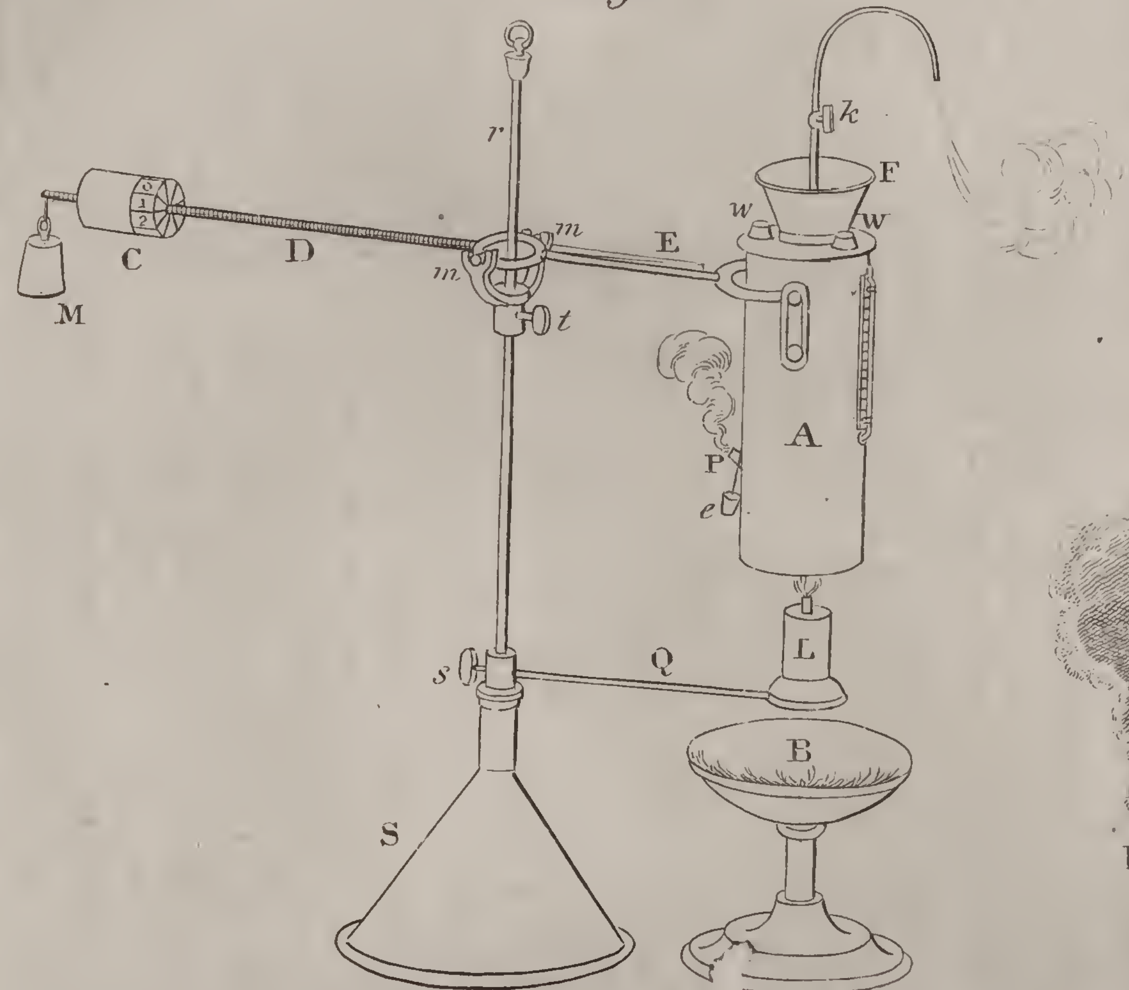


Fig. 2.

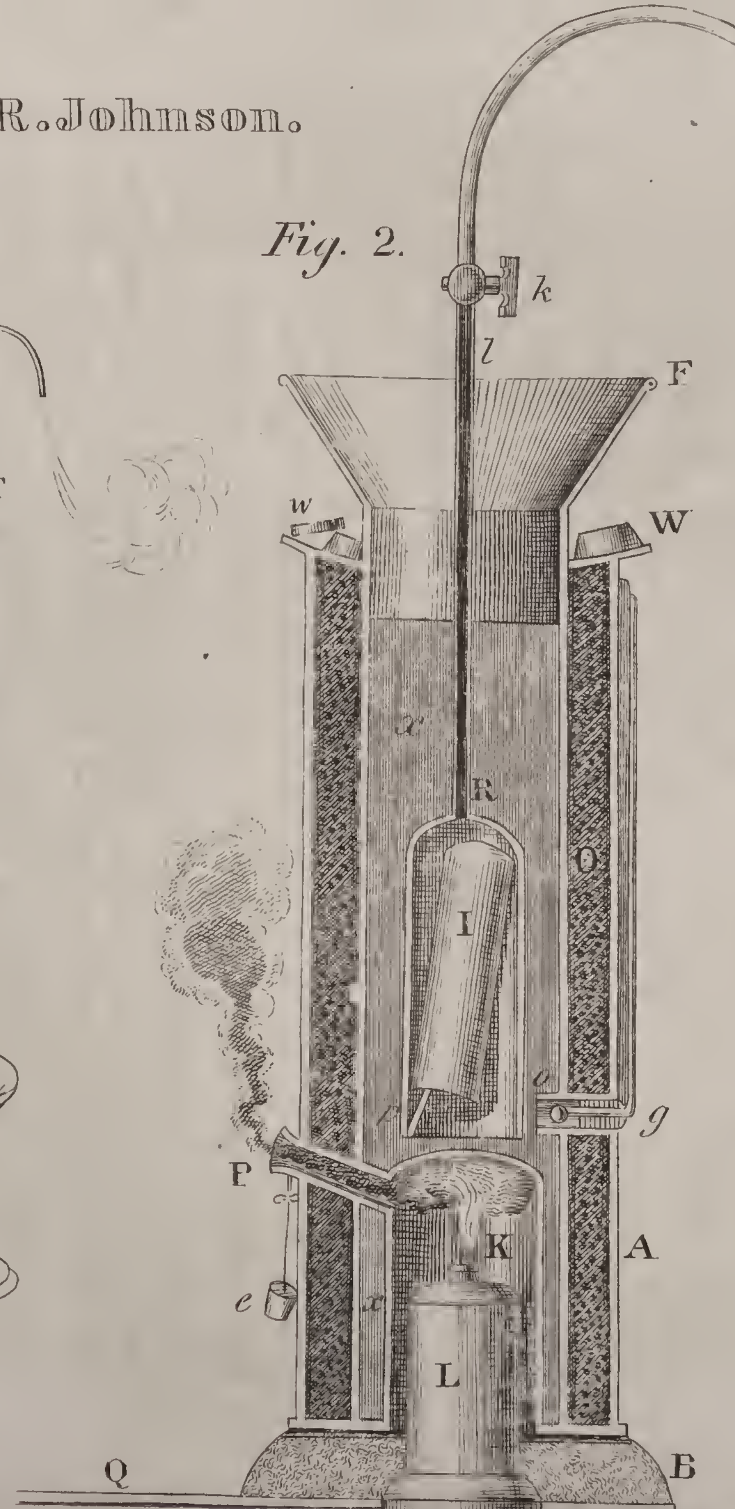
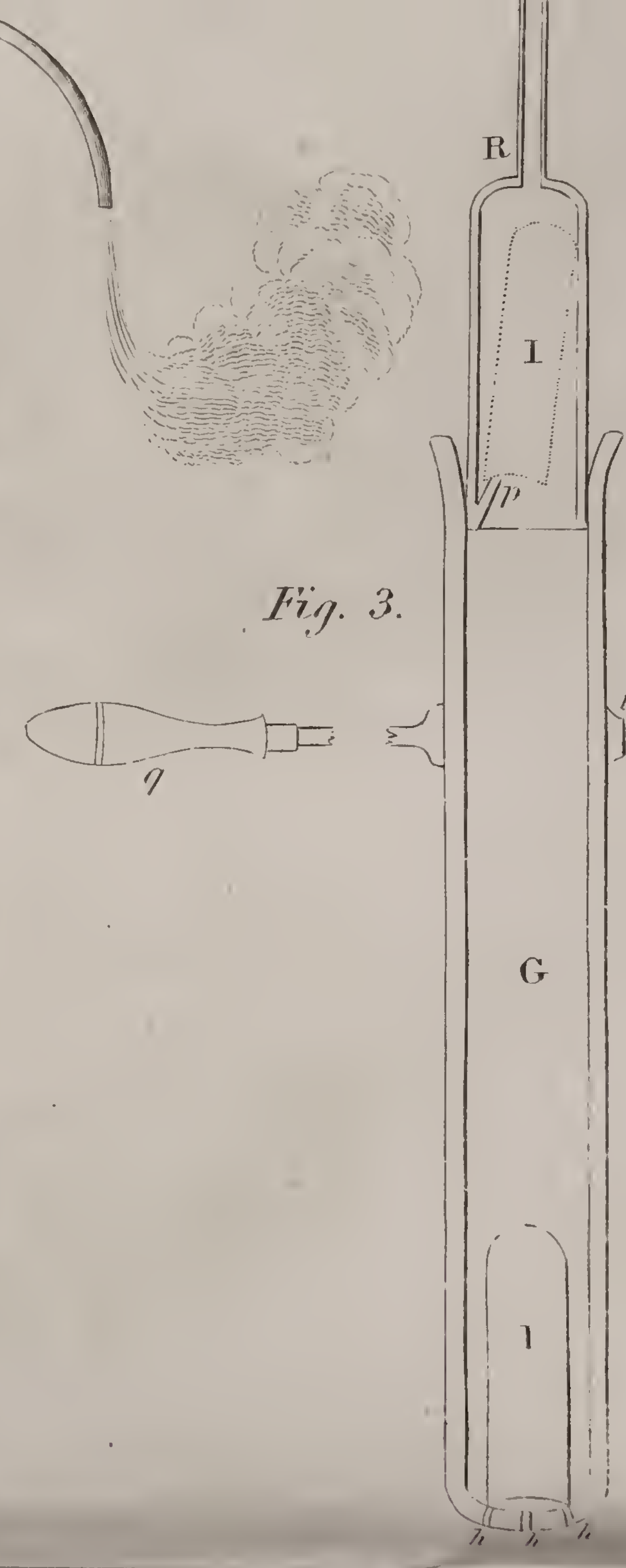


Fig. 3.



It will be no less easy to solve the same problem by means of a Gunter's scale and a pair of compasses. The distance from 1 to the constant fraction, (1.4732 in the above case,) on the *line of numbers*, will reach from the number of grains of steam to the temperature, in degrees Fahr., above 212°.

We might, instead of determining the specific heat of the *standard mass*, by the ordinary methods, first heat it to a known temperature in boiling mercury, in oil, spirits of turpentine, melting zinc, lead, bismuth, tin, or any convenient alloy* of these metals, and then observe the quantity of steam it produces in cooling down to 212°. The actual temperature of the liquid being known by observation, and the quantity of steam by weight, every other quantity of vapor given by different temperatures of the same standard mass, will be produced by a proportionate quantity of heat. It will be seen that this method of proceeding takes no account of differences in specific heat at *different temperatures*. It comes at once to a simple expression of the heating power of a body measured by a *single effect* of the heating principle, that of conferring the elastic form on water, already raised to the boiling point.

It will readily be conceived that the question of specific heats, of expansion, and contraction, and of course the variable rates of expansion at different temperatures might be wholly disregarded, if we had an invariable standard by which to measure the portions of heat, that may at any time be present in a given portion of matter. The latent heat of vapor supplies this standard. The following are some of the different results which have been obtained by those who have made experiments on this subject.

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* The alloys of tin and lead are very convenient for this purpose. Their melting points as determined by M. Kupffer, (See Ann. de Chim. et de Phys. XL. 302; and Thomson on Heat and Electricity, p. 174.) are as follows:

Tin	*Alloy of*	Lead	Point of fusion.
1 atom	+	1 atom - - -	466°
2 "	+	1 " - -	385
3 "	+	1 " - - -	367
4 "	+	1 " - -	372
5 "	+	1 " - - -	381

The alloy commonly employed by tin plate workers is I believe composed of 1 tin, +2 lead. The mean of several trials with that alloy have convinced me that its melting point is 385°.

Latent heat in vapor.	Determined by
950°	Watt.
945	Southern.
1000	Lavoisier and Laplace.
1040.8	Rumford.
955.8	Despretz.
above 1000	Thomson.
1000	Ure, (corrected result.)
mean 984	

I have in the preceding calculations assumed the latent heat, at 990°. Should the results of Dr. Ure, which appear to have been made in a manner as unexceptionable as any yet published, be confirmed and established by other philosophers, the facility of making calculations such as I have above presented, will be increased and the usefulness of the principle in pyrometry more fully established.

Note.—The experiment on melted iron, on page 50, is offered *chiefly* as an *illustration.* The apparatus then at hand did not admit of all the exactness which the case allows;—still the result is believed to be nearly correct.

From the American Journal of Science and Arts, No. 1. Vol. XXIII.

REMARKS

ON THE

STRENGTH OF

CYLINDRICAL STEAM BOILERS.

BY WALTER R. JOHNSON,

Prof. of Nat. Phil. in the Franklin Institute—Philadelphia.

Read before the Institute, at the stated monthly meeting, July 26, 1832.

REMARKS, &c.

It has been generally supposed that the rolling of *boiler-plate* iron, gives to the sheets a greater tenacity in the direction of the length, than in that of the breadth. Supposing this to be correct, it has frequently been asked, how the sheets ought to be disposed in a cylindrical boiler of the common form, in order to oppose the greatest strength to the greatest strain. It has also been asked, whether the same arrangement will be required for *all diameters*, or whether a magnitude will not be eventually attained, which may require the direction of the sheets to be reversed?

To determine these questions in a general manner, recourse must be had to mathematical formulas, assuming such symbols for each of the elements as may apply to any given case of which the separate data are determined either by experiment or by the conditions of the case. The *principles* of the calculation require our first notice.

1. To know the force which tends to burst a cylindrical vessel in the longitudinal direction,—or, in other words, to separate the *head* from the curved *sides*, we have only to consider the actual area of the head, and to multiply the number of units of *surface* by the number of units of *force* applied to each superficial unit. This will give the total *divellent* force in that direction.

To counteract this, we have, or may be conceived to have, the tenacity of as many longitudinal bars as there are linear units in the circumference of the cylinder. The united strength of these bars constitutes the total retaining or *quiescent* force, and at the moment when rupture is about to take place, the *divellent* and the *quiescent* forces must obviously be equal.

2. To ascertain the amount of force which tends to rupture the cylinder along the curved side, or rather along two opposite sides, we may regard the pressure as applied through the whole *breadth* of the cylinder upon each linear unit of the diameter. Hence the total amount of force which would tend to divide the cylinder in halves by

separating it along two lines, on opposite sides, would be represented by multiplying the diameter by the force exerted on each unit of surface, and this product by the length of the cylinder. But even without regarding the *length*, we may consider the force requisite to rupture a *single band*, in the direction now supposed, and of one linear unit in breadth; since it obviously makes no difference whether the cylinder be long or short in respect to the ease or difficulty of separating the sides. The *divellent* force, in this direction, is therefore truly represented by the diameter multiplied by the pressure *per unit of surface*. The retaining or *quiescent* force in the same direction, is only the strength or tenacity of the two opposite sides of the supposed band. Here also, at the moment when a rupture is about to occur, the *divellent* must exactly equal the *quiescent* force.

3. In order to estimate the augmentation of *divellent* force, consequent upon an increase of diameter, we have only to consider that as the diameter is increased, the product *of the diameter and the force per unit of surface*, is increased in the same ratio. But unless the thickness of the metal be increased, the *quiescent* force must remain unaltered. The *quiescent* forces, therefore, continue the same; the *divellent* increase with the diameter.

4. Again, as the diameter of the cylinder is increased, the area of its end is increased in the ratio of the *square* of the diameter. The *divellent* force is therefore augmented in this ratio. But the retaining force does not, as in the other direction, remain the same, since the *circumference* of a circle increases in the same ratio as the diameter. The *quiescent* force will consequently be augmented in the simple ratio of the diameter, without any additional thickness of metal, so that on the whole the total tendency to rupture in this direction will increase only in the *simple* ratio of the diameter.

5. Since we have seen that the tendency to rupture, in both directions, increases in the simple direct ratio of the increase of diameter, it is obvious that any position of the sheets which is right for one diameter, must be right for all. Hence, there can never be a condition, in regard to mere magnitude, which will require the sheets to be reversed.

6. The foregoing considerations being once admitted, we may proceed to ascertain what is the true direction of the greatest tenacity in the sheet, if any difference exist, and to what that difference *might* amount, consistently with equal safety of the boiler in both directions.

7. Let x= the diameter of the cylinder; f= the force or pressure per unit of surface, (pounds per square inch, for example;) T= the tenacity of metal, which with the diameter x and the force f will be required in the linear unit of the circumference, in order to hold on the head. Then, the whole *quiescent* force will be $3.1416x\mathrm{T}$, while the *divellent* will be $.7854x^2f$; consequently $.7854x^2f=3.1416x\mathrm{T}$, as above stated. Dividing by $.7854x$, we have $xf=4\mathrm{T}$; and we derive immediately $x=\frac{4\mathrm{T}}{f}$, $f=\frac{4\mathrm{T}}{x}$, $\mathrm{T}=\frac{xf}{4}$. That is, the tenacity of the *longitudinal bar of the assumed unit in width, will be one fourth of the product of the diameter into the pressure*, measuring the tenacity by the same standard as the pressure, whether in pounds or kilogrammes.

8. Now assuming the tenacity required in the *circular band* of the same width to be t, we shall, agreeably to what has already been said, have the *divellent* force expressed by xf and the *quiescent* by $2t$, so that $xf=2t$ and $t=\frac{xf}{2}$; also $f=\frac{2t}{x}$, and $x=\frac{2t}{f}$. Having thus obtained two expressions for each of the quantities x and f, we may by comparing them, readily discover the relative values of T and t; thus, $x=\frac{4\mathrm{T}}{f}$ and $x=\frac{2t}{f}$, hence $\frac{4\mathrm{T}}{f}=\frac{2t}{f}$, and $4\mathrm{T}=2t$ or $t=2\mathrm{T}$. From which it follows, that, *under a known diameter, and with a given force or pressure, the tenacity of metal in a cylindrical boiler of uniform thickness, ought to be twice as great in the direction of the curve as in that of the length of the cylinder, and that if this could be the case the boiler would still have equal safety in both directions.* In whichever direction, therefore, the rolling of the metal gives the greatest tenacity, in the same direction must the sheet always be bent in forming the convexity of the cylinder. It follows that if we suppose the tenacity precisely *equal* in both directions, the liability to rupture, by a mere internal pressure, *ought to be twice as great along the longitudinal direction as at the juncture of the head.* This supposes the strain regular and the riveting not to weaken the sheet.

9. To know how large we may safely make a cylindrical boiler, having the absolute tenacity of the metal, in the *strongest direction*, and with a known thickness, we have only to revert to the formula $x=\frac{2t}{f}$. That is, *the diameter will be found by dividing twice the*

tenacity by the greatest force per unit of surface, which the boiler is ever to sustain.

10. When, knowing the absolute tenacity of a metal or other material reckoned in weight, to the bar of a given area, in its cross section, we would determine the *thickness* of that metal which ought to be employed in a boiler of given diameter and to sustain a certain force, we may use the formula $t=\frac{xf}{2}$, and, dividing the latter member of this equation by the *strength* of the square bar, which we may call s, we obtain the thickness demanded in the direction of the curve, which we may denominate p, so that $p=\frac{xf}{2s}$; this will give the thickness of the boiler plate, either in whole numbers or decimals. Thus, suppose the diameter of a cylindrical boiler is to be 36 inches,—that it is to be formed of iron which will bear 55000 lbs. to the square inch, and is to sustain 750 lbs. to the square inch;—what ought to be the thickness of the metal? Here $x=36, f=750, 2s=110,000$; consequently, $p=\frac{36\times750}{110000}=.2454$, or a little less than one quarter of an inch.

11. It must, however, be evident that the *minimum* tenacity, of any particular description of metal, is that on which all the calculations ought to be made, when there is any probability that the actual pressure will, in practice, ever reach the limit assigned as the value of f in the calculation.

If we had plates of different metals, or of different known degrees of tenacity in the same kind of metal, and were desirous of ascertaining how strong a kind we must employ under a limited *thickness*, *diameter* and *pressure*, we should decide the point by transforming the formula $p=\frac{xf}{2s}$ into $ps=\frac{xf}{2}$, and then into $s=\frac{xf}{2p}$. In other terms, in order to know the strength of the metal required, or the direct strain which an inch square bar of the same ought to be capable of sustaining, we must *multiply the diameter of the boiler in inches by the pressure per square inch in pounds, and divide the product by twice the intended thickness in parts of an inch.* Thus, how strong a metal ought to be employed to sustain a pressure of 1000 lbs. to the square inch, in a boiler 30 inches in diameter and one quarter of

an inch thick? Here $s=\frac{30\times1000}{2\times.25}=60{,}000$. Hence we see that the metal must be capable of sustaining *sixty thousand pounds* to the inch bar, or in that proportion, for any other size. This formula enables us to determine whether among the metals of known tenacity *any* one can be found to fulfil the conditions under the thickness assigned.

12. On the basis of the foregoing formulas, the following table of diameters, thicknesses of iron, and strains to the inch of metal, in both directions, has been formed. It is obvious that the *actual* tenacity of the metal employed in a given case must be of the greatest importance to the result. The extensive series of experiments recently undertaken by the Institute to determine this question, in reference to different kinds and varieties of boiler plate, and with regard to the various circumstances of its manufacture and application, will hereafter furnish us with important data to aid in applying the formulas to each separate case. I shall for the present assume the tenacity of an inch square bar of rolled iron at 55000 lbs. in the direction of the length of the sheet. Supposing the pressure generally employed in cylindrical high pressure boilers to be 150 lbs. to the square inch, agreeably to the practice in this city, the table is calculated upon the principle that the boiler ought to have five times as great a strength as it is ordinarily required to exert. The calculation is upon a continuous sheet of metal, without seams in any direction. The thicknesses are given in *ten-thousandths* of an inch; but in practice the last figure may be omitted without material error.

Diameter of the boiler in inches.	Thickness of plate iron which will bear 55,000 lbs. to the square inch required to resist the strain in the direction of the curve under a pressure of 750 lbs. to the square inch, calculated by the formula $p=\frac{xf}{2s}$.	Corresponding tenacity of each inch wide ring or band required to support a pressure of 750 lbs. to the square inch, calculated on the formula $t=\frac{xf}{2}$.	Tenacity required in each longitudinal bar of one inch wide, to sustain the pressure tending to burst out the head, calcalated on the formula $T=\frac{xf}{4}$.
Inches.	Inch.	Pounds.	Pounds.
1	.0068	375	187.5
2	.0136	750	375
3	.0204	1125	562.5
4	.0272	1500	750
5	.0341	1875	937.5
6	.0409	2250	1125
7	.0476	2625	1312.5
8	.0545	3000	1500
9	.0613	3375	1687.5
10	.0681	3750	1875
11	.0745	4125	2062.5
12	.0818	4500	2250
14	.0954	5250	2625
16	.1090	6000	3000
18	.1227	6750	3375
20	.1363	7500	3750
22	.1490	8250	4125
24	.1636	9000	4500
26	.1773	9750	4875
28	.1909	10500	5250
30	.2045	11250	5625
32	.2182	12000	6000
34	.2318	12750	6375
36	.2455	13500	6750
38	.2591	14250	7125
40	.2727	15000	7500
42	.2860	15750	7875
44	.2980	16500	8250
46	.3116	17250	8625
48	.3252	18000	9000
50	.3388	18750	9375

13. I am not aware that this subject has been previously treated in a general manner, at least as it regards several of the points above presented. Mr. Oliver Evans made some particular calculations of the strength requisite to sustain the pressure in a boiler of known dimensions, under a tension of 1500 lbs. to the square inch. In the

table at p. 27 of his "Young Steam Engineer's Guide," he has given calculations for seventeen different diameters of boilers, with the power which, at each diameter, the steam would exert "to break every ring of one inch wide in any one place," and "the thickness of the sheets of *good iron* necessary to hold the power." His table is formed on the supposition that sheet iron will bear 64,000 lbs. to the square inch, and would consequently lead to considerable *excesses* if strictly applied in practice. To six of the diameters he has annexed the "power exerted on the heads to burst them out, in pounds weight." These he has calculated in the usual manner, by multiplying the area by the pressure per inch. Opposite to *three* of the numbers just mentioned, he has added "the strength of the boiler to hold the head on, in pounds weight." These he has calculated on the supposition that the metal had equal tenacity in all directions. On this supposition, and on the principles above developed, each of those three numbers should have been exactly double of that against which it stands in the preceding column. Neither of the three is so, precisely; but the first and third come as near it as could be expected, considering that the thickness is expressed only in hundredths of an inch, while the second is too small by more than a million of pounds. These errors would not, I apprehend, have occurred had the author adverted to the general principle above developed, in regard to strength required of the metal in the two directions.

The following extract from the table just alluded to, will illustrate the preceding remarks: a column of corrected results has been added.

Diameter of the boiler in inches.	Power to break each ring of 1 inch, pressure being 1500 lbs.	Thickness of the plate of iron sustaining 64,000 lbs. to the square inch.	Power exerted on the heads.	Strength to hold on the heads.	Corrected numbers to be substituted for those of col. 5, agreeably to the foregoing remarks.
42	31,000	48	2,077,500	4,052,400	4,155,000
36	27,000	42	1,525,500	2,037,440	3,051,000
20	15,000	23	471,000	918,777	942,000

The very general use, in this country, of strong cast iron *heads*, fastened to the wrought iron *cylinders* by broad flanches extending some inches within the latter, there riveted and subsequently further secured by a strong wrought iron hoop, driven on when hot and *shrunk* by cooling,—appears to obviate the necessity of examining the question in regard to the best form and necessary thickness of

wrought iron heads. I have lately seen, at the Philadelphia Water Works, the range of boilers, constructed several years ago, on the above principle, by Oliver Evans himself, removed, on account of their use having been superseded by water power. Although these boilers had been for several years employed under a pressure of 100 and 150 lbs. per square inch, yet the heads did not appear to have suffered in the least degree from exposure to this force. Hence the French instructions, forbidding the use of plain cast iron heads for pressures above 1½ atmospheres, do not seem to be founded on sufficient experience of their actual value.

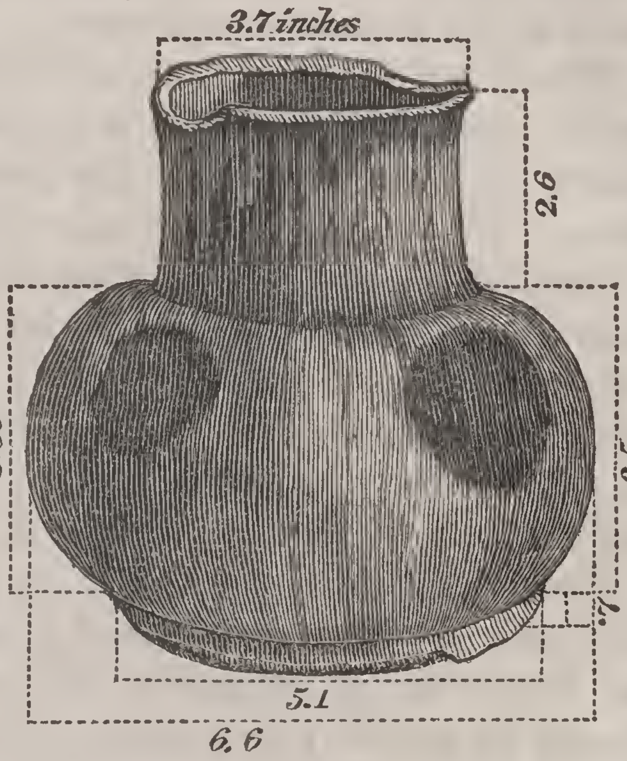
Notice of an Ancient American Utensil; by Prof. Walter R. Johnson.

Philadelphia, August 9, 1832.

TO PROFESSOR SILLIMAN.

Dear Sir—The early state of the arts among the aborigines of this country, is a subject of much interest to the American antiquary. Under this impression, I take the liberty of forwarding to you the following description, and the accompanying sketch, of an article of American manufacture, of a date probably anterior to the time of any European discoveries on the North American continent—perhaps anterior even to the age of mounds and mummies. For the donation of this interesting relic of antiquity, I am indebted to the kindness of Mr. Isaac Rawlings, of Memphis, in Tennessee. He informs me that it was found near his residence, some eight or ten years ago, after one of those extensive falls of the river bank, which are known to be frequent along the line of the Mississippi. It had been buried several feet beneath the surface, and was brought to light by the *avalanche.* The materials of this piece of Indian pottery are blue clay and white particles of a soft, friable substance, resembling calcined and pulverized shells. The exterior has neither glazing nor coating of any kind, but only such a degree of smoothness as would be likely to result from long use and much handling. It does not appear to have been formed upon a potter's wheel, nor indeed to have received the effects of any machinery in its manufacture, but the hand which *moulded* it, must have been not a little skilled in the production of such articles, as the figure will sufficiently indicate. Time appears to have produced but little effect upon

the materials. The figure will show two slight fractures of the rim, and the scaling off of the whole exterior part of the base, except on one side.



At four points, on the upper portion of the body, and equidistant respectively from each other, are four flattened spots, each about 1.5 inch in diameter, and, with one exception, marked by a darker color than the rest of the vessel. Two of these spots are seen in the figure. The depressions were obviously made in the moist state, and, together with the color, may have resulted from the arrangement used in burning or *baking* the ware; by which means these four points were more pressed than others, while soft, and less exposed to the fire, when hot, than other parts of the vessel. Hence the carbonaceous or other coloring matter, may not have been so completely expelled from these parts of the surface.

Articles of this description must, at a very remote period, have been common in that part of the country whence this was taken. In the Philadelphia Museum are two jugs or bottles, composed of similar materials, found in Tennessee, at the depth of fifteen or twenty feet below the surface of the ground. Several specimens of the same ware, are also contained in the collection of the Philosophical Society, in this city. Some of the latter, and one of those in the Museum, bear a near resemblance in form to an egg, with one end opened and extended a little, to constitute a neck and mouth. The most rude and apparently the most ancient specimens have generally this form; which may *possibly* have been suggested to the mind of the savage, together with the very idea of earthen ware itself, by the previous use of egg shells for some domestic purposes. None of the specimens of pottery above referred to, appear to have received any glazing—a remark which, as far as my observation has extended, is likewise applicable to the Mexican and South American pottery. The latter occasionally exhibit a species of varnish very durable in its nature, but entirely distinct from a true gla-

zing. This observation is in conformity with the opinion of Mr. Abraham Miller of this city, whose practical acquaintance with this branch of art has led him to a careful examination of many specimens of the ancient manufacture.

The dotted lines and figures in the cut indicate the several dimensions. That the vessel was not formed by revolving machinery is shown by the difference in the depth of the body on two opposite sides. The contents of the vase are three and a half pints. From its peculiar composition and manufacture, it sends forth when moistened a fresh earthy odor, exactly like that which is perceived at the commencement of a sudden shower, at the close of a hot summer's day. As a drinking vessel, this circumstance may have enhanced its value in the eyes of the Indian, who thus regaled his sense of smell exactly as when he quaffed from the pure native spring.

I have been thus particular in the above description, from a belief, that when collected, figured and described, objects of this kind may aid in forming an estimate of the state of the arts and civilization among the nations which possessed this continent at periods of very remote antiquity, and may perhaps furnish an *index* to mark the relationship of the American Indians, either with each other, or with distant nations of the globe.

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ON THE METHODS OF DETERMINING AND CALCULATING THE SPECIFIC HEATS OF CERTAIN SOLIDS, WITH SOME PRECAUTIONS TO BE OBSERVED IN THE EXPERIMENTS.

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ON THE METHODS, &c.

THE practice which formerly prevailed, of presenting to the public, statements respecting the *results* of philosophical experiments without a detail of the exact methods adopted for their attainment, and the precautions employed to avoid error, has in many instances involved the necessity of *repetition*—long and laborious, of what ought, once for all, to have been definitively settled. The *verification* of a philosophical truth, by a method unlike any previously employed, is a matter entirely different from the processes just referred to; and however well we may be satisfied of a truth, established in one manner, there will always be found both pleasure and profit in attaining the same general conclusions, by methods and considerations independent of each other. There is not perhaps a better illustration of this remark than the variety of methods which may be employed for determining the specific heat of solids. The earliest was that of *mixture*, and consists in immersing the solid at a known temperature, in water (or some other liquid,) at a temperature either above or below its own. The temperature lost by the hotter body, and that gained by the cooler, will, with proper corrections, give, when compared, the specific heat of the body under trial.

The next method, that of Lavoisier, employs, instead of the rise or fall of temperature in water, the latent heat of *water passing from a state of ice* and the weight of this solid, which any other given solid will melt while cooling from any known temperature down to the melting point, is the measure of its specific heat, which, being referred to the quantity of ice which a mass of water, equal to that of the solid, would have melted in cooling the same number of *degrees*, gives us the numerical expression of the specific heat of the solid.

The *third method* employs the cooling power of air, and the *times* which will be required to depress the temperatures of the different solids through a fixed range of the thermometer are taken as the indices of the specific heat. This is the method employed by Pro-

fessor Meyer on the woods and by Prof. Leslie and Mr. Dalton on other bodies.

The *fourth method* employs the heat which becomes latent when water is rapidly converted into vapor at its *boiling point*, by the direct and sole agency of the solid, heated to a known temperature *above* that point. This method may be successfully employed to determine the latent heat of melting metals as well as their specific heat from 212° to their melting points, and also their change of capacity, if any, after they have passed into the liquid state. The weight of boiling water which they will under different circumstances convert into vapor, compared with the effect of the same amount of water, conceived to be heated to the same temperature as the solid, gives again the numerical expression of the specific heat.

It is evident, that if this fourth method be adequate to give the specific heat when the temperature is known, it is also competent to give the temperature when the specific heat is known; but in order to remove all doubt as to its applicability to the latter purpose, it is well to ascertain by different and independent methods the exact index of the specific heat, whether uniform or variable, of the solids which may be employed for this purpose. Among the substances adapted to this end, are pure malleable iron and pure platina. They are both highly indestructible, when heated without the access of foreign ingredients, such as oxygen, sulphur, carbon, silica, &c., and though the specific heat of the former is represented by some writers as increasing pretty rapidly, with the temperature, yet this increase is not by any means in so great a ratio, as that of its dilatations, which other authors have proposed to employ as standards for measuring very high temperatures. As to platina, its specific heat is low, and its increments of rate, both in dilatation and specific heat, are represented as very moderate. I may here remark that the experiments of Dulong and Petit on this subject appear to have been erroneously stated in one part of their prize memoir, which has doubtless led to the supposition that they discovered no increment of capacity in platina by the elevation of temperature. In their table of the specific heats of the different metals at 100° and at 300° Centigrade, as originally published in the Annales de Chimie, Vol. VII, we find .0355 placed under both of those temperatures against *platina*. The same numbers are transferred into every English edition of works in which I have seen that table, with the single exception of Turner's Chemistry, in which the number is .0335 both for

100° and 300°. Yet in a subsequent table of the memoir, Petit and Dulong have given the indications of thermometers formed of the different metals, on the basis of their specific heats, compared with those of an air thermometer at 300°, and they have put down that of platina 317.9, which it obviously could not be, if its specific heat were invariable, but supposing that heat to increase from .0335 at 100° Cent. to .0355 at 300°, the indication ascribed to it would be correct. In a recent edition of Turner's Chemistry, by Dr. Bache of this city, this error has been corrected.

But, to return to the subject of iron, we find, in the various works of philosophers, a remarkable discrepancy between their statements of the specific heats of this metal. The following are among the results obtained by the different individuals whose names are annexed.

On iron of sp. gr. 7.876, the specific heat was found,	.1260	by Wilcke.
" soft bar iron, sp. gr. 7.724, - - -	.1190	" Gadolin.
" sheet iron, - - - - -	.1090	" Lavoisier.
" iron, of what quality not specified, - -	.1250	" Kirwan.
" do. do. do. - - -	.1269	" Crawford.
" do. do. do. - - -	.1450	" Irvine.
" do. do. do. - - -	.1300	" Dalton.
" cast iron, abounding in plumbago, - -	.1240	" Gadolin.
" white cast iron, - - - -	.1320	" do.
" iron, (kind not specified,) between 32° and 212° F.	.1098	" Petit and Dulong.
" do. do. do. do. 32 " 392	.1150	" do. do.
" do. do. do. do. 32 " 572	.1218	" do. do.
" do. do. do. do. 32 " 662	.1255	" do. do.

The mean of these thirteen numbers is 0.12377. The wide discrepancies are probably owing to the circumstances under which the authors respectively operated, and to physical differences in the metal. Nor is the disagreement confined to these results; for while Crawford and Irvine contend that the specific heats of bodies remain constant, at all temperatures, Dalton, Dulong and Petit maintain that they increase with the increase of temperature. But it seems difficult to reconcile this supposition with another result of Petit and Dulong, viz. that the specific heat of all bodies is inversely as their atomic weight, unless we could suppose what is manifestly absurd, that the atomic weight varies with the temperature, or that in different bodies the *rate of increase in specific heat* varies always inversely as the atomic weight. Thus, if H were supposed the specific heat of any body and A its atomic weight, and if dH were the increment of specific heat for a given rise of temperature, then not

only must $AH =$ the constant C, but also $A(H+dH)$ must$=C'$, and of course $AdH=C''$,—in order that another body having the atomic weight a, and a specific heat h, should give $ah=C$, $a(h+dh) =C'$, and $adh=C''$. Let us observe how far their table of the increase of specific heat between 212° and 572° Fahr. will bear out this supposition. The atomic weights are those given by Petit and Dulong themselves, with the exception of those of mercury and antimony, which are derived from Dr. Thomson.

Metals.	Atomic weights.	Petit and Dulong's difference of specific heats between 212° and 572° F.	Values of C″ from these data.
Mercury,	12.5	.0020	.025000
Antimony,	5.5	.0064	.023100
Platinum,	11.26	.0020	.022520
Silver,	6.75	.0054	.036450
Copper,	3.957	.0064	.025280
Iron,	3.392	.0120	.040704
Zinc,	4.03	.0088	.035464

To attribute the character of "*constants*" to such numbers as are found in the fourth column of this table, would be little satisfactory to any who were not prone to uphold a theory at all hazards. Even the apparent correspondencies between mercury and copper, antimony and platina, silver and zinc, are probably mere accidental coincidences. Iron, on which the authors to whom I have referred, appear to have bestowed most attention, gives a result far removed from all the rest and nearly double to some of them.

The foregoing considerations, together with the use to be made of the specific heat of iron and platina in generating vapor for pyrometrical measurements have induced me to attempt a re-examination of certain parts of this subject, and for this purpose I have taken the method originally adopted by Wilcke and Black, viz. that of immersing the hot metal in cold water, in connection with the fourth method above described, that of using the latent heat of vapor to ascertain the specific heat when the temperature of the solid is known.

In experiments of this nature several precautions are to be observed, and a considerable number of sources of error anticipated, against which, if we cannot directly guard, we must provide for them the necessary corrections.

1. *We must attend to the character and condition of the metal*, its freedom from alloys or impurities, its specific gravity, its freedom

from foreign matter on the surface, particularly from *vaporizable* matters, which may, by being converted into vapor in passing from the source of heat to the cold water, essentially diminish the temperature, or, if in any considerable quantity, may aid in elevating that of the water, and thus give a result too high. I have been sometimes embarrassed by this source of error. In a series of eight experiments, made by heating in a bath of oil on a given mass of wrought iron, at a mean temperature of 236° Fahr., the temperature of the room being 76° and that of the water at commencement 74.86° in a glass vessel of known specific heat, containing at every trial the same weight of water, and measuring the temperatures every time by the same thermometers, I obtained as the mean result .12332,—the lowest being .12131, when the iron was immersed at 192°, and the highest .12920, when the metal was at only 190°.

To ascertain how far this source of error would be obviated by adopting a bath of mercury, I made eight experiments in the same glass vessel, on the same piece of iron, and with all other circumstances corresponding to the former set, except that the temperature of the metal at immersion was at a mean of 323¾°, and of course the specific heat, according to Dulong and Petit, ought to have come out higher than in the other series, instead of which it was at a mean of .12217, the lowest being .12119 at 338°, and the highest .12499 at 350°, the higher temperature giving the higher result.

2. *The second precaution relates to the condition of the water used in the experiment.*—The specific heat of saline solutions and earthy mixtures being different from that of water, care should be taken that only pure water be employed. That which has been recently distilled should be preferred as it is less likely to be charged with air than that which has been long exposed in open vessels. If any considerable quantity of air contained in the liquid be suddenly expanded it may rise to the top and escape carrying with it the portion of heat which has given it so much enlargement of bulk. This would cause an error *in deficiency.*

3. *The temperature and hygrometric state of the air in which the experiment is conducted*, require attention. It is obvious that if we commence the experiment at a temperature below the dew point of the air, the vessel will be accumulating moisture *before* and *during* the experiment, and if it remain but for a short time at the initial temperature before the hot body is immersed, the consequence will be, that the latent heat of the vapor being employed in elevating

the temperature of the water, the latter receiving from 1000 to 1200 degrees of heat, for every unit of water condensed, will cause an error *in excess.* If however the vessel have remained in its cold state for some time, and then received a considerable elevation of temperature from the hot body, the whole exterior of the vessel will act as the wet bulb of a thermometer, and tend to keep the temperature of itself and its contents down to the *evaporating point.* This would cause a serious error *in defect.* Both these errors are obviously to be avoided by not allowing the temperature of the vessel to sink below the dew point. In regard to the relative temperatures of the vessel and the surrounding air, we must observe that as the latter part of the process, when the solid and the water are approaching an equilibrium, goes on very slowly, it will be necessary to commence our experiment with the water nearly as much below the actual temperature of the apartment as the increase of temperature is expected to be, in order to terminate as little as may be above the surrounding air. These two conditions of beginning above the dew point and never ending much above the temperature of the air can be complied with only when the air is tolerably dry. Such should therefore be the state of weather selected for experiments of this nature.

4. *The construction, magnitude, and specific heat of the thermometer,* used to measure the temperature of the water, is an object of some consequence in the determination of this delicate question. To carry entire accuracy into the subject it will be necessary to know the separate weights of the materials which compose it, and their several specific heats, and further to allow for an amount of water precisely equivalent to that part of the thermometer which is immersed during the experiment. In obtaining a thermometer for this purpose I caused the tube to be carefully measured and weighed before the bulb was blown, to ascertain its weight per inch in length, then knowing the length used to form the bulb it was easy to ascertain the number of grains of glass *immersed* in any given experiment. By again weighing after the thermometer was filled, the weight of mercury it contained was exactly known, and by weighing the *scale* separately and knowing its specific heat, the *equivalent in water* was found answering to any portion of the whole instrument, which may be entered along the scale near the thermometric degrees. The necessity of allowing for a *scale* may however be obviated by using a naked-bulb thermometer provided the *range* be sufficient without including the naked part of the stem. But to attain this end and at

the same time possess the requisite subdivision of degrees the bulb must be large, or the stem very long. Could we employ a cylindrical metallic containing vessel, fitted up with an apparatus to measure its own longitudinal expansions with perfect accuracy, it would perhaps be the best kind of thermometer for such experiments. The specific heat of mercury, at least within the range where a thermometer for our present purpose would be used, is, according to the four independent determinations of Lavoisier, Kirwan, Crawford and Dulong, .0327. The specific heat of glass given by six different philosophers is at a mean .18511, that of Irvine being .2000, and that of Kirwan .1740 at the extremes. By three trials on flint glass in a method hereafter to be referred to, I obtained a mean of .17854, which is *less* than the above mean result by .00657 and *more* than that of Dulong and Petit by .00154.

If the scale be of brass we have its specific heat by the mean result of Wilke, Crawford and Dalton's determinations .11276, but as the conducting power of that metal is high as well as its rate of expansion it ought if possible to be avoided as a part of the immersed thermometer.

The thermometer which measures the heat of the solid before immersion, should be faithfully compared with that which is used in the water. Thermometers of extensive range are often found inaccurate from containing minute portions of air. It would for this reason be desirable to compare their indications with the fusing points of tin and lead, as well as the boiling points of water and mercury. To be sure of at least two points in the temperature of the hot body it will be well to place it in an iron vessel containing mercury, immersed in boiling water, for *that* point, and in a bath of melted tin immersed in boiling mercury to get the utmost range of temperature measurable by that liquid. By forming a suitable covering for the bath of mercury, and providing for the exit and condensation of its fumes we may operate with perfect convenience in the method just described.

6. I have already mentioned the necessity of confining the range of temperature taken by the water during these experiments. If we terminate the experiment but one or two degrees above the actual temperature of the room the loss by radiation and conduction on one side will in general be so nearly counteracted by the gain on the other, as to influence very little, the actual result. But if we employ too small a vessel the high temperature of our solid may give too

great an elevation, and then we shall have not only the radiation and conduction of the vessel but the tension of vapor at the surface of the water, and the latter will be greater or less according to its greater or less distance from the dew-point. The actual absolute loss may be found by a separate experiment on exposing the vessel and water for some hours to the same temperature as that at which the trial took place and in an atmosphere having the same hygrometric tension. The weight lost during the longer exposure compared with its length of time ought to be proportionate to the loss and time in the other case. The number of grains of vapor would then be multiplied by its latent heat at the generating temperature, to obtain the absolute effect in cooling the mass from which it rose. This error like that occasioned by the escape of air and that by the evaporation of dew from the surface of the vessel will be *in defect.*

7. The nature of the vessel containing the water, its surface, specific heat and the space it leaves open to the air. It should be of such dimensions as to be completely filled when the thermometer and the body under trial are immersed in the water. If of metal, its perfect homogeneity is to be attained, and if of glass the specific heat should be separately ascertained.

8. To guard the hot body from loss of heat in passing from the source of heat to the cold water I make use of a thick sheet-iron cylindrical shield which is kept constantly immersed in the melted metal with the piece under trial and conveys it to the very mouth of the water vessel into which it is lowered by a fine wire or thread enabling the operator to move it from one part of the vessel to the other.

9. The vessel and its contents must be weighed with the greatest attainable accuracy at every trial. No reliance should be placed on the apparent levels of the fluid. Graduated measures are entirely out of the question in trials of this kind. To adjust the weight with readiness I employ a dropping tube with a fine point and instead of a piston use a species of micrometer screw, to force out the liquid or draw it in at pleasure. Drops weighing one third of a grain may be easily obtained by this instrument. The method of *substitution* is adopted in weighing to avoid all inaccuracy in the beam of the balance.

10. A result is not to be taken as established until it can be reproduced, at least, within the limits of the errors of observation. I feel assured that much of the erroneous matter which has been published on this subject has arisen from a want of due care and patience

in repetition. Before closing these observations it may be proper to add, that when in any given experiment the thermometer which measures the temperature of the water is withdrawn to insert the hot body and afterwards returned to the liquor, it will, under certain circumstances of the air, be found to have changed its indication, the moisture remaining upon its surface causing it to take the "*evaporating point*" as its stationary position. In this case it must be noted on again immersing the bulb, and the change it has undergone recorded and subsequently multiplied by the *equivalent* of the immersed part of the thermometer to obtain the requisite correction.

The table exhibiting the data, calculations and results of experiments to determine specific heats in the manner above described, will contain the following particulars. 1st. The number of the experiment; 2d. The kind of heating liquid employed; 3d. The dew point of the apartment; 4th. Its evaporating point; 5th. The weight of solid under trial; 6th. The temperature at which it is immersed; 7th. Temperature of the water; 8th. Temperature of the thermometer when immersed; 9th. Temperature of the air; 10th. Resulting temperature of the water; 11th. Gain of temperature by the water containing vessel and thermometer; 12th. Loss of temperature in the solid; 13th. Time occupied by the experiment; 14th. Weight of water in grains; 15th. Equivalent of the containing vessel in grains of water; 16th. Equivalent of the part of thermometer immersed; 17th. Sum of the equivalents in water, containing vessel and thermometer; 18th. Product of the preceding column by the gain of temperature; 19th. Product of the weight of solid by its loss of temperature; 20th. Correction obtained by multiplying the equivalent of the thermometer by its variation from the *initial temperature* of the water. (This correction will be either positive or negative, according as the evaporating point is below or above the initial temperature.) 21st. Specific heat obtained by dividing the 17th column, *corrected*, by the 18th. Other corrections may be inserted when necessary according to the observations already made. To present the several cases to which we have referred in the preceding remarks, the following formulas may be adopted.

1. When the specific heat of the containing vessel is to be ascertained by first filling it with water of a known temperature and letting it stand until we are sure that a stationary point has been attained, then emptying it and instantly refilling with water of a different tem-

perature; if the expansion of the vessel could be made to measure its own increase or diminution of temperature we should have the simplest of all possible cases; for calling

$w=$ the weight of water in grains,

$T=$ the degrees of change in temperature which it undergoes,

$g=$ the weight in grains of the containing vessel,

$t=$ the change of its temperature by the experiment, and

$x=$ the specific heat of the material of which the vessel is composed, that of water being unity, we shall have $TW=gtx$ or $x=\frac{TW}{gt}$ (1). This supposes the experiment to be made with such regard to the thermometric and hygrometric state of the air as to require no correction on that account.

2. If we introduce a mercurial thermometer, with a brass scale, to measure the change of temperature, putting

$b=$ the weight of brass immersed,

$m=$ the weight of mercury,

$c=$ the weight of the glass bulb and that part of the stem which sinks into the water, we have, for the equivalent of the thermometer in grains of water, the following expression, $.11276\,b+.0327m+.18511c$, and as by suspending the thermometer or otherwise fixing it in a certain position for many experiments, we can always use the same part of its length, we may substitute for this complex term the simple expression c for the thermometrical equivalent in grains of water; then the formula (1) will become $x=\frac{T(W+e)}{gt}$ (2). It was by this method of trial and calculation that the three experiments before mentioned, gave .17854 for the specific heat of glass, though in the expression for the thermometer I have chosen to use the mean of six other determinations until I can repeat and vary the experiment, so as to be satisfied which is nearest to the truth.

3. The specific heat of the containing vessel being known, we proceed to that of any other solid, wrought iron for example, putting its weight in grains $=i$, and its specific heat $=z$. T will now represent the change of temperature not only of the water and thermometer but also of the containing vessel, and t the change of the solid, i, g, x and e being the same as above, then will $itz=T(w+gx+e)$ and $z=\frac{T(w+gx+e)}{it}$ (3), or the formula may be simplified

by representing the three terms $w+gx+e$ by W$'$ whence $z=\frac{\mathrm{TW}'}{it}$, (4). To this, as before stated, we must apply a correction if the thermometer be not at the same temperature when immersed, as the water was when the solid was plunged into it. Calling the difference d we have the correction $\pm de$, as before stated, according as the thermometer was below or above the water, and hence the formula becomes $x=\frac{\mathrm{T}w'\pm de}{it}$ (5).

4. If the specific heat of the solid under trial and of the containing vessel be the same, (as when a vessel of untinned sheet iron is employed to hold the water,) we may then if the *specific heat* be supposed not to vary within the limits of our experiment, employ the following expressions in which z is the specific heat of both, the solid and the water vessel; T, w, and e remaining as in (3), we obtain the equation $itz=\mathrm{T}(w+e+gz)=\mathrm{T}(w+e)+\mathrm{T}gz$, and by transposition $itz-\mathrm{T}gz=\mathrm{T}(w+e)$, whence $z=\frac{\mathrm{T}(w+e)}{it-g\mathrm{T}}$, (6).

5. But if, instead of making the container of the same material as the body under trial, we choose to form it of any other kind, even of one whose precise specific heat is not yet known, we may, by using vessels of *different* thicknesses and the *same* liquid content, ascertain by successive experiments under otherwise similar circumstances, the specific heat of the material which composes the vessel. Thus two jars capable of containing the same weight of water may be formed of glass from the same melting pot, but one possessing two or three times the thickness of the other. We may then heat the same mass of iron twice (or any number of times) to the same temperature, and immerse it in water at the different trials in each of the two vessels at the same temperature. Then putting

$w=$ the weight of water contained in each glass,
$g=$ the weight of the thicker glass,
$g'=$ that of the thinner,
$x=$ the unknown specific heat of glass,
$\mathrm{T}=$ the change of temperature of water and glass when g is used,
$t=$ the change of temperature of iron when g is used,
$\mathrm{T}'=$ the change of temperature of water when g' is used,
$t'=$ the change of temperature of iron when g' is used,
i, as before, $=$ the weight of iron,

$z=$ its specific heat,

$e=$ the equivalent of the thermometer.

Then, as the temperature of the water, the air, and the iron, are supposed to be the same in both cases, we shall have by the two expressions,

1. $z=\frac{\mathrm{TW}'\pm de}{it}=\frac{\mathrm{T}(w+e+gx)\pm de}{it}$,

and 2. $z=\frac{\mathrm{T}'w'\pm de}{it'}=\frac{\mathrm{T}'(w+e+g'x)\pm de}{it'}$;

from which we derive

3. $\frac{\mathrm{T}(w+e)+\mathrm{T}gx\pm de}{t}=\frac{\mathrm{T}'(w+e)+\mathrm{T}'g'x\pm de}{t'}$. Hence

4. $\mathrm{T}t'(w+e)+\mathrm{T}t'gx\pm det'=\mathrm{T}'t(w+e)+\mathrm{T}'tg'x\pm tde$, and by transposition,

5. $\mathrm{T}t'gx-\mathrm{T}'tg'x=(\mathrm{T}'t-\mathrm{T}t').(w+e)\pm(t\mp t').de$, and by division,

6. $x=\frac{(\mathrm{T}'t-\mathrm{T}t').(w+e)\pm(t\mp t')de}{\mathrm{T}t'g-\mathrm{T}'tg'}$, which, if there be no correction for thermometric variation, will be reduced to the simpler form,

7. $x=\frac{(\mathrm{T}'t-\mathrm{T}t').(w+e)}{\mathrm{T}t'g-\mathrm{T}'tg'}$, (7). And as the value of x is now found, we may substitute it in either the first or second equation, to enable us to find the value of z. The first would give, (omitting the correction $\pm de$.)

8. $z=\frac{\mathrm{T}(w+e)+\mathrm{T}g\left(\frac{(\mathrm{T}'t-\mathrm{T}t').(w+e)}{\mathrm{T}t'g-\mathrm{T}'tg'}\right)}{ti}$. Had we taken the second equation in which to substitute the value of x, the value of z would have been $=\frac{\mathrm{T}'(w+e)+\mathrm{T}'g'\left(\frac{(\mathrm{T}'t-\mathrm{T}t').(w+e)}{\mathrm{T}t'g-\mathrm{T}'tg'}\right)}{t'i}$. From either of these we may obtain

9. $z=\frac{\mathrm{TT}'(g-g').(w+e)}{i(\mathrm{T}t'g-\mathrm{T}'tg')}$. (8.)

The necessity of applying the correction $\pm de$, arises from the liability of the warm current of liquid ascending from the hot metal to elevate the temperature of the thermometer above that which ought to be exhibited by the liquid when the maximum effect of the solid has been attained. By taking the thermometer out of the

water at the instant the metal is immersed, and keeping it out till near the conclusion of the experiment, we not only have a better opportunity to agitate the liquid, but also avoid the deception just referred to.

If the experiment be commenced precisely at the *evaporating point,* the bulb of the thermometer covered with a film of water will be retained at that point and no correction required.

The formula for the fourth method of determining specific heat, which may serve as a *verification* of the one just presented, is founded on the fact that the *weight of vapor* generated by a given weight of metal is proportionate to the *weight, temperature,* and *specific heat* of the metal employed. The experiments in this case all terminate at the *boiling* point, but may commence at any known *superior* temperature. The result obtained will therefore be the mean specific heat between the temperature of boiling water, and that at which the metal enters the liquid. Calling

$i=$ the weight of metal employed,

$t=$ its temperature above boiling point at immersion, and

$z=$ its mean specific heat, from boiling point to the temperature at which it is immersed; also,

$v=$ the weight of vapor produced by the action of i, and

$l=$ the latent heat of vapor from water boiling in the open air at the time and place of the experiment.

Then, by the above statement, we have (supposing no heat lost by any other means than vaporization) the *effect* $=vl$, and the *cause* $=it$. The latter is on the supposition that the experiment ceases, and the loss of weight in water is ascertained, the moment the metal has come down to the boiling point. Hence $itz=vl$, and $z=\frac{vl}{it}$. (9.)

Also, as above stated, the temperature t can be found when z is known; thus, $t=\frac{vl}{iz}$. (10.)

Collecting the foregoing formulas into a single view, we have the following table.

No. of the formula.	Purpose of the experiment and calculation.	Expression in terms above explained.
(1.)	To find the spec. heat of a container, measuring temperature by its own expansion.	$x=\frac{\mathrm{T}w}{gt}$.
(2.)	To find the same when a mercurial thermometer is used.	$x=\frac{\mathrm{T}(w+e)}{gt}$.
(3.)	To find sp. heat of a solid, and correcting for the water vessel.	$z=\frac{\mathrm{T}(w+e+gx)}{it}$.
(4.)	To express the same, reducing water, thermometer, and container to W′.	$z=\frac{\mathrm{TW}'}{it}$.
(5.)	Do. corrected when the thermometer differs from initial temperature.	$z=\frac{\mathrm{TW}'\pm de}{it}$.
(6.)	Do. when the container is of the same material as the solid under trial.	$z=\frac{\mathrm{T}(w+e)}{it-\mathrm{T}g}$.
(7.)	To find sp. heat of the container, by trials in two vessels of unequal weights,	$x=\frac{(\mathrm{T}'t-\mathrm{T}t').(w+e)}{\mathrm{T}t'g-\mathrm{T}'tg'}$.
(8.)	To find sp. heat of the solid from the same trials as the preceding.	$z=\frac{\mathrm{TT}'(g-g').(w+e)}{i(\mathrm{T}t'g-\mathrm{T}'tg'}$.
(9.)	To obtain the sp. heat of a solid from its vaporizing power.	$z=\frac{vl}{it}$.
(10.)	To find the temperature of the solid by vaporization when the specific heat is known.	$t=\frac{vl}{iz}$.

Numerous experiments on all branches of the subject have already been made, and others are in progress, the whole of which will in due time be laid before the public.

From the Journal of the Acad of Natural Sciences of Phila

On the fusing point of Zinc, and a reference to the relation between the tenacity and the fusibility of the metals in general. *By* WALTER R. JOHNSON, A. M., Mem. Acad. Nat. Sci. Phila., Prof. of Mech. and Nat. Phil. in the Frank. Inst., &c.

Read Nov. 1st, and 22d, and Dec. 6th, 1836.

THE elevated temperature at which zinc is fused, and the imperfection of the means formerly employed to determine the melting points of the more obdurate metals, prevented the attainment of the same precision in regard to it, which was found practicable in the case of lead, tin, bismuth and their alloys.

GUYTON MORVEAU, by means of his platina expansion pyrometer, had fixed the melting point of zinc, at 705.25 degrees of Fahrenheit. His instrument depended for its action on the difference in the expansions of a plate of baked porcelain and one of platina. That his determination of the melting point of zinc is inaccurate, may be inferred from the fact, that he places the temperature of *red heat* in *daylight* at 517° Fahrenheit;

whereas, it is well known that redness does not begin to appear, even in the dark, until we have considerably exceeded the boiling point of mercury; which, measured by the expansion of that liquid, corrected for the dilation of glass, was found by Mr. Crichton, to be 660° Fahrenheit.

Mr. Daniel measured the expansion of zinc from 62° to 212°, and from 62° to 662°, as also from the first mentioned point to that of its fusion,—and taking the amount of the two former expansions as the measures of the temperature of fusion, he found it to be 848°, when the expansion to 212° was applied; and 960°, when that to 662° was taken for the standard. On applying to this metal, however, his *pyrometer*, which is founded on the difference of expansion between platina and plumbago, he found the degree indicated for the fusing point of zinc to be 773°; thus differing from Morveau by an excess of about 68°, while in his determination of the fusing point of other metals of high melting points, he falls below Morveau. In the case of cast iron, this difference amounts to 5217 degrees; Daniel giving for the fusing point of that metal only 3479°, while Morveau gives 8696°. In the publications of the Society for the Diffusion of Useful Knowledge, the fusing point of zinc is said to be 700°. Having, in the course of some investigations with the steam py-

rometer, become satisfied that the temperature at which iron is distinctly red in daylight, is stated too low by the writers on that subject, and that the temperature of melting zinc is rather below than above that point, I felt desirous of testing the correctness of the generally received statements.

With this view, several experiments were made by plunging the standard piece of the pyrometer into a mass of melted zinc, contained in a cylinder of wrought iron; continuing it there for 15 or 20 minutes, allowing the iron container and the zinc in the mean time to be kept just above the temperature of fusion, so that the standard piece could be withdrawn without impediment. When taken from the melted mass, some portion of zinc usually adhered, much the greater part of which, however, was readily removed by a smart blow or two given with a rod of iron to the standard piece while suspended by the wire. The portion (usually a few grains,) which still continued to adhere, served, by solidifying, to show the moment when the iron had cooled to the point of the congelation of zinc. When that was attained, the standard piece was plunged into the boiling water of the pyrometer, the weight of vapour which escaped was ascertained in the usual manner, and the quantity of zinc which adhered was subsequently found, by

weighing the standard piece with the pelicles of zinc still adhering, and deducting its previous, known weight. This was then added to the apparent weight of vapour which had escaped, and by allowing a correction for the weight of adhering zinc and its known specific heat, it was easy to arrive at a just calculation of the temperature of the iron at the moment of immersion.

In this manner were made several successive trials, in neither of which did the standard piece, at the time the zinc ceased to be fluid upon its surface, present the least luminousness in daylight, but as it had been a little before withdrawn from the bath of melted zinc, which had just ceased to appear luminous, it is conceived that this point could not be far remote,—probably not more than 100 or 150 degrees.

In the first experiment, the number of parts of vapour read from the revolving counterpoise was 776; the number of parts of zinc adhering, 105; for which the correction to be added to the observed weight is 92; and as the experiment, in all cases, terminates at 212°, this number is to be added to the sum of the others in order to obtain the fusing point on Fahrenheit's scale = 1080°. Suspecting that the immersion might have been made a little too soon, or before the true solidifying point had been attained, I made a second trial,

in which the iron was not immersed until it was so far cooled as to prevent the adhering zinc from being scraped off with a knife. This trial yielded the result of 953° for the melting point; conceived to be too low.

A third trial, in which the efforts to remove the zinc were not persevered in quite so long as in the preceding case, gave 1032°. Admitting the possibility that the last experiment was still a little above the truth, we may combine it with the preceding, to obtain a mean for the approximate temperature of melting zinc, viz.: 993°.

If we knew any temperature at which heat ceased to exert an influence adverse to the cohesion of a metal, that point might obviously be assumed as the maximum of tenacity; and, as at the point of fusion all tenacity is overcome, the gradual advance from no tenacity to the maximum, might be marked by the degrees of heat below the point of fusion at which trials of tenacity are made; since it is obvious that whatever mechanical force we apply to overcome tenacity will be so much less than the force at maximum tenacity, as the quantity of heat employed to assist us is the greater. It will be my object, in the succeeding part of this paper, to trace, at least approximately, the law of tenacity, as dependent on this principle, in some of the more fusible metals.

The metals selected were tin, lead, bismuth, and an alloy of tin and lead. On these four materials were made several experiments at ordinary temperatures, and, on some of them, other trials, at points above or below the range of atmospheric variations.

Experiment 1. The first experiment was on a bar of stream tin, cast, at a temperature not much above the melting point, into a mould one foot in length, of uniform area of section throughout its length. The figure of the cross section was a trapezium, the two opposite and parallel sides of an having lengths differing about one inch from each other. The area of this cross section was .385595.—This bar required to draw it asunder 2417.5 lbs., equal to 6282 lbs. per square inch. The area of the section of the fracture was .26714 of a square inch, and the amount of constriction, consequently a little more than $\frac{2}{7}$ of the whole.

Exp. 2. This experiment was made on a different bar from the preceding. In order to reduce the temperature of the bar below that of the air, it was enclosed in snow closely packed around the bar, leaving only a small portion of each end projecting, for the purpose of attaching it to the opposite parts of the machine employed as a test. When connected, the coupling parts of the appa-

ratus, as well as the bar, were surrounded with snow closely packed, and the whole wrapped with several folds of linen cloth, to sustain the snow and guard in part against radiation and the contact of the air. Having allowed sufficient time for the whole apparatus to attain a uniform temperature, the force was applied, and it was found that the fracture took place much more slowly than in the first experiment, and gave a result of 6504 lbs. per square inch.

Exp. 3. In order to guard against any error which might be assigned to the last experiment when compared with the first, in consequence of the two having been made on different specimens of the cast tin, I now caused the machine to take hold of another part of the bar, which had been broken at 32°, and, on applying the weights at a temperature of 50°, it gave way with a force of 6258 lbs. per square inch.

Exp. 4. At the temperature of 50° the same bar again gave a result identical with that which had been obtained in the *first* trial, viz.: 6282 lbs. per square inch.

In all these experiments, it was observed that the section of fracture was irregular and jagged throughout.

In comparing the experiments of Mr. RENNIE with the mean of 3 of those above cited at 50°—52° of temperature, we find a difference of no less than 1538 lbs. per square inch, by which the result of that experimenter falls short of that which I have obtained. The result of Mr. EMERSON was very near that above given, viz.: 6255.

In seeking the cause of such discrepancies as that between Mr. RENNIE and myself, we must look to other grounds than the accidental impurities of the metal, or varieties in the mode of applying the force. It is probably to be found in the temperature at which the bars were severally cast.

Exp. 5. Another bar, having a cross section of .405816, was cast at a somewhat higher temperature than the preceding. When tried, it was found to yield a result of 6040 lbs. per square inch. In the course of the operation upon this bar, it was observed that the first permanent elongation did not take place, until rather more than $\frac{2}{3}$ of the breaking weight had been applied. In order to render the influence of the casting temperature still more unequivocal, I cast several bars, at temperatures varying from that already described to a bright red heat. The result was, that a gradual diminution of the tenacity of the bars when

cold was observed, conforming apparently to the slowness with which the metal finally became congealed, and the consequent perfection with which the crystalline arrangement was allowed to be assumed.

Exp. 6, 7, 8. On three several bars cast very hot, but below redness, were obtained the following results, viz.:

1 at 52°	exhibiting	strength of	5208
1 at 62	"	"	5174
1 at 66	"	"	5174
		Mean of the three	5185

In all these cases the fracture exhibited regular crystalline arrangements, particularly in the interior portion of the section. The outer coat of the metal was however generally amorphous, and as the force was very gradually applied and could at pleasure be arrested before the exterior coat of fibres parted, the latter often exhibited the appearance of a hole quite through the bar in the direction of its thickness, the fibres at the edges and corners still continuing to retain their hold and extend themselves after the central, and more perfectly crystalline mass had given way. Another interesting circumstance was also observ-

able; the crystalline arrangement had a dividing plane cutting the centre of the bar in the direction of its breadth.

Exp. 9. A bar was cast at a temperature above redness into the mould previously heated, but below the melting point of tin. This bar gave a result of 5062 lbs. per square inch, at the temperature of 59°. Hence it appears that the influence of casting temperature may extend to about $\frac{1}{6}$ of the tenacity of that which is cast but little above the melting point, the higher casting temperatures giving the lower tenacities.

In order to compare the experiment at 32° with those which were subsequently made on *hot-cast* bars, it is necessary to do it through the medium of those trials at 50°—52° which were made on bars of the same character as the one tried at the freezing point. Thus 6274 : 5185 : : 6504 : 5375 = the strength of the hot-cast bars at 32°.

Having thus in some measure ascertained the effect of the mode of preparing the specimens, I proceeded to investigate the tenacity of bars cast at a high temperature, when subsequently heated above the ordinary range of the atmosphere. For this purpose the bars were made to pass through a bath of water kept hot by a spirit-lamp.

Exp. 10, 11, 12. In this manner were made three experiments; one at 122°, giving a strength of 3510 pounds per square inch; and two others, at 212°, giving respectively 2476 and 2328 pounds; mean 2402. The elongation of the bars was, in these cases, confined to the part in the hot water. The nature of the fracture was similar to that observed on the hot cast bars, when tried at low temperatures. From what has just been stated, it is evident that at 122° the strength of tin is but little more than three-fifths of what it is at 60°, and at 212° it is less than half as much as at 60°. In accordance with what has been already stated, we may now consider the difference between the melting point of tin and each of the above temperatures, as a series of quantities, corresponding with which is another series representing the tenacities at those temperatures respectively. It is evident that if the tenacity be a simple function of the *temperature below the melting point*, two points will be sufficient to establish the law, but if it be found that the function itself is variable, in other words, that the curve representing the correspondencies between the temperatures and tenacities has a point of inflection, we shall be only able to examine it by discussing several points on each side of the inflection. I will first present a table of the experiments thus far detailed.

No. of experiment.	Mode of casting.	Area of section.	Temperature at time of trial.	Strength in lbs. per sq. inch.	Date.[4]
1	Cool, into cold mould.	.385595	52°	6282	1836, March 5
2	do.	do.	32°	6504	do.
3	do.	do.	50°	6258	do.
4	do.	do.	50°	6282	do.
5	do.	.405816	52°	6040	March 7
6	Very hot, not red.	.385595	52°	5208	do.
7	do.	do.	61°	5174	April 2
8	do.	do.	66°	5174	April 9
9	Red hot into hot mould.	do.	59°	5062	April 17
10	Hot, not red.	do.	122°	3510	April 2
11	do.	do.	212°	2476	do.
12	do.	do.	212°	2328	do.

By comparing the above calculated result on a hot-cast bar, broken at 32°, with the experimental results on the same bar, broken at 60°, as deduced from experiments 6, 7 and 8; at 122°, as given by experiment 10; and at 212°, as obtained from the mean of experiments 11 and 12, we get the following series of temperatures below melting point, the correspondent tenacities in pounds per square inch, and the function of temperature

below fusing point, which represents the tenacity.

No. of the comparison.	Temperature of the experiment.	Degrees below the fusing point of tin.	Tenacities in lbs. per square inch.	Log. of the degrees below fusing.	Log. of the tenacity.	Power of the temperature representing the tenacity.
1	32	410	5375	.6127839	.7303785	1.206
2	60	382	5185	.5820634	.7147488	1.409
3	122	320	3510	.5051500	.5453071	1.690
4	212	230	2402	.3617278	.3805730	1.352

The above powers of the temperature, which represent the correspondent tenacities at the different parts of the thermometric scale, are derived from a comparison of each experiment with every one of the others, by the formula $\phi = \frac{\text{Log}\,c - \text{Log}\,c'}{\text{Log}\,t - \text{Log}\,t'}$; where ϕ is the power sought, t a given distance on the scale of temperature below the fusing point, t′ another, but less distance below the same point, c the cohesion at the temperature t, and c′ the cohesion at t′. It has sometimes been supposed that a certain relation existed between the temperature of fusion, the tenacity, and the specific gravity of metals. In order to test the correctness of this supposition, I made a few experiments on other metals, the melting points and specific gravities of which are known. It has been shown above, that the law of tenacity for tin, as dependent on temperature, is not a *simple rela-*

tion, identical throughout the scale; and the fusing points of different metals are at different distances from the ordinary temperature of the air. Their laws of tenacity, commencing from their respective melting points, *may* also be different one from another; and even if alike, still two metals must, at any assumed point of the scale, be found at very different distances apart, from what they would be at another point of the same scale.

From these considerations, it is easy to foresee that if it should so happen that the specific gravity of a metal multiplied by its tenacity at one temperature, gave a product representing its fusing temperature, and that another metal should have such a tenacity at the same point, and such a specific gravity as, when the two were multiplied, would give a result corresponding to *its* melting temperature, still it would not follow that at all other temperatures the tenacities multiplied by the respective specific gravities, would give results proportionate to the same quantities, that is, to the fusing temperatures.

If the tenacity of tin, as a solid, were taken at 442°, it would be found 0; but that of lead, at the same temperature, being 170° below its melting point, would be an appreciable quantity, probably not less than one-sixth or one-eighth of

its cohesion at 60°. Again, the cohesion of mercury at —39° is 0; below that point, it becomes sensible, and probably goes on increasing according to some law, with the decrease of temperature; iron at —39° is, according to the generally received opinion, weaker than at +32°; in other words, it has, if this opinion be correct, passed its maximum of tenacity, by an abstraction of heat, before mercury has begun to receive tenacity by the same means. The specific gravities of the two substances have, in the mean time, undergone no such change as essentially to affect the product obtained by multiplying it by the *tenacity*. In the following table, the tenacities, excepting for zinc and silver, were obtained from my own experiments. The fusing points of the first three metals in the table are derived from other experimenters; that of wrought iron is taken from the mean of two experiments by different methods, given by Clement and Desormes, who used for *measures*, the melting of ice, and the heating of water, in the two cases respectively. The other melting points, viz.: those for zinc, copper, silver, cast iron, and the alloy of tin and lead, are the results of my experiments, principally with the steam pyrometer.

Experiments.	*Names of metals.*	*Tenacity at 60 d. Fahr. in lbs. per sq. inch.*	*Specific gravity at 60 deg.*	*Fusing point by experiment.*	*Fusing point by Cloud's formula F=TD.*	*Specific heat of the metal.*	*Atomic weight of the metal.*
1	Bismuth.	2328	9.880	506	269	.0288	71
2	Lead.	3215	11.385	612	426	.0293	103.6
3	Tin.	5185	2.799	442	442	.0514	57.9
4	Zinc.	2600	7.000	993	212	.0927	32.3
5	Copper.	32.826	8.986	2828	3445	.1043	31.6
6	Wrought iron.	57.525	7.77	3945	5220	.1133	28.
7	Alloy,* tin and lead. 1 T.+3 L.	3.991	9.944	514	463		
8	Pure silver.	41.500	10.470	2194	5074	.0557	108.
9	Cast iron,	27.000	7.248	3080	2285	.1205	

A comparison of the 5th and 6th columns demonstrates the justness of the preceding remarks, making it evident that no relation, such as has been conjectured to prevail, exists between the specific gravities, tenacities, and fusing points of

* This alloy was in the state contemplated in this investigation at the temperature here noted; but for a considerable distance below that temperature it was in a kind of semi-fluid state, like that of a liquid thickened up with some fine grained solid, and appeared to have its stationary point, or at least *one such point*, at about 500°. The original investigation of the question relating to stationary points in the cooling and solidification of metals and alloys, was made by Rudberg. See *Annales de Chim. et de Phys.* vol. 48, page 353. Subsequent experimenters have, it is believed, added little to his discoveries.

the metals.* The specific heats and atomic weights are annexed in the table to facilitate the comparison of these elements with the tenacities; but it is believed that on them no satisfactory law of tenacities can be founded. In the formula at the head of the 6th column, F is the fusing temperature; T, the tenacity, and D the density of the metal. The melting point of tin is the standard of comparison between the proportional numbers obtained by the formula.

* This *supposed* relation was founded on the erroneous measures of temperature, formerly applied to determine fusing points. The calculation of some fusing temperatures on this principle, and a general statement by which to calculate others, is found in the Transactions of the American Philosophical Society, Vol. I. New Series, p. 168. The paper alluded to was read May 20, 1814.

EXPERIMENTS

ON THE

ADHESION OF IRON SPIKES OF VARIOUS FORMS,

WHEN DRIVEN INTO DIFFERENT SPECIES OF TIMBER.

BY PROF. WALTER R. JOHNSON.

FROM THE JOURNAL OF THE FRANKLIN INSTITUTE.

In reference to rail-road constructions, bridge building, and several other useful applications in civil engineering as well as in naval architecture, the adhesion of spikes, bolts, and nails of various forms becomes an object of much practical importance. With regard to rail roads this matter is worthy of more attention than might at first sight be supposed. Owing to the present high price of iron, the flat rail is often unavoidably adopted in preference to the edge rail, and whenever the speed of a train, descending by gravity or impelled with great velocity by the moving power, is to be suddenly checked by the brake, the friction of the periphery of the wheel on the rail tends to drive the latter lengthwise and thus to force all the spikes with which it is fastened, into closer contact with the ends of the fibres which have been cut in driving them. If this partial or total dragging of the wheels along the rails takes place, sometimes in one direction, and sometimes in the other, the spikes must be subjected to alternate impulses on opposite sides. Indeed, whenever the motive power depends on friction for its efficacy, as in the case of the common locomotive engine, there is a constant succession of these two opposite dragging forces, the engine constantly tending by its driving wheels to urge the rail backward, and the train by an equal, but more extensively distributed action, tending to urge forward all the rails over which it is, at the same moment, passing. So decided is this influence, that on a rail-road where the transportation is all in one direction, and where the cars descend by gravity; I have seen rails entirely detached, or loosely connected but by a single spike, while others clearly indicated by the inclined position of their upper faces or heads, that they were pressed into an oblique or leaning position in the wooden sill. This single case may serve to show the importance of attending to the character of the spikes used in similar constructions.

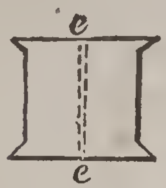
To determine some of the points relating to the form of spikes, and the kind of timber into which they are driven, the following experiments were undertaken; they serve to show the relative economy of each form of spike, as well as its absolute fitness for the purpose intended.

The mode of executing the experiments was to drive each spike to a certain distance, above its cutting edge, into the edge of a piece of plank or scantling, and, by means of a suitable apparatus adapted to that purpose, to draw it out by a direct longitudinal strain. The machine employed for this purpose was the same as that which has been used for testing the strength of iron and copper in experiments on the tenacity of materials employed in steam boilers. A strong band or strap of iron connected with the weighing beam of that machine held the piece of plank, and a clasped pincers with a suitable jaw, for taking hold of the head and projecting part of the spike, was attached to the opposite part of the machine, which being

tightened by a strong screw, held the spike firmly while the application of weights upon the longer arm of the lever drew the timber away and released the spike. Care was taken to cause the strain to pass through the axis of the spike, and by a very gradual application of weights, to avoid surpassing that force which was just sufficient for its extraction.

The first experiment was upon one of Burden's patent square spikes with a cutting edge, intended to be, in all cases, placed across the grain of the timber. This spike was .375 inch square, and was driven into a sound plank of seasoned Jersey yellow pine $3\frac{3}{8}$ inches. The force required to extract it was 2052 lbs. The exact weight of the part driven into the wood was 866 grains troy.

The second trial was upon a flanched, grooved and swelled spike, having the grooves between two projecting wings or flanches on the same sides as



the faces of the cutting edge. The other two sides were planes continuing to the head. A cross section of this spike taken $1\frac{3}{4}$ inches above its edge or point had the form of the figure annexed. At $\frac{8}{10}$ of an inch from the edge, that is where the flanches project least or where the *swell* between them comes nearest to forming a perfect square, the figure is as follows:—the dotted line *e e* in each figure representing the direction of the cutting edge.

Towards the head of this spike, the flanching and grooving is suppressed and the form becomes a square. This experiment was made on the same piece of Jersey yellow pine as the first, and the weight required for extracting the spike was 1596 lbs.; the weight of the part driven in was $708\frac{1}{4}$ grains. The cutting edge was ragged and irregular. The distance to which it was driven was $3\frac{3}{8}$ inches, as in the first trial. To know the relative values of the two forms of spikes we have but to divide the weight required for the extraction of each by the number of grains in the part which had been buried in the wood. Thus $2052 \div 866 = 2.37$, and $1596 \div 708.25 = 2.112$. Hence the plain spike had an advantage over the swelled and grooved one in about the proportion 23 to 21. It should be mentioned, also, that the plain spike was drawn out by a very gradual addition of force; whereas the force of 1596 lbs. drew the grooved spike immediately after its application. In the first trial an attempt was made to detect any yielding or gradual retreat of the spike before the final start, but none was perceived.

The third and fourth experiments were made with the same spikes respectively as the first and second; but instead of yellow pine the timber employed was thoroughly seasoned white oak.

The plain spike driven $3\frac{3}{8}$ inches into that timber, required for its extraction a force of 3910 lbs., and, as before, exhibited no signs of movement until the instant of starting, when it suddenly came out about a quarter of an inch, or as far as the range of motion, and the elasticity of the machine would permit.

The flanched, swelled and grooved spike driven $3\frac{3}{8}$ inches into another part of the same piece of plank, from which the plain one had been extracted, was drawn out with a force of 3791 lbs. A slow motion to the extent of $\frac{1}{25}$ or $\frac{1}{20}$ of an inch was in this trial perceived to precede the starting of the spike; and was accompanied by a gradual protrusion of the fibres of the timber immediately around the iron.

In these experiments though the plain spike bore the greater absolute weight, yet, when the weight of metal is considered it is seen that the relative values of the two are 4.515 in the plain, and 5.354 in the grooved form.

The various circumstances of the four preceding experiments are seen at a single view in the following table.

Table I.

No. of the experiment.	Description of spike used	Kind and condition of timber.	Breadth of the spike.	Thickness of the spike.	Depth to which it was driven.	Weight in grains of the part driven in.	Force required to extract it in lbs. avoirdupois.	Ratio of the extracting power to the w'ht of spike	Date.	Remarks.
			inch.	inch.	inches.					
1	Plain square spike, (Burden's.)	Seasoned Jersey yellow pine.	.375	.375	3.375	866	2052	2.368	Oct. 27, 1835	Force gradually applied; no motion previous to the start.
2	Flanched, grooved and swelled	Do.	.375	.300	3.375	708	1596	2.254	Do.	Force applied; at once.
3	Burden's plain.	Seasoned white oak.	.375	.375	3.375	866	3910	4.515	Do.	Started suddenly
4	Grooved and swelled.	Do.	.375	.300	3.375	708	3791	5.354	Do.	Fibres protruded 1-20 of an inch before the spike drew out.

Hence it appears that in yellow pine the grooved and swelled form was about five per cent. less advantageous than the plain, while in the seasoned oak the former was $18\frac{1}{2}$ per cent. superior to the latter. It is also apparent that the advantage of seasoned oak over seasoned yellow pine for retaining spikes is, by a comparison of experiments 1 and 3, as 1 to 1.9; and by a comparison of 2 and 4 it is as 1 to 2.37. In the preceding experiments the spikes were driven into the timber and immediately drawn out again. In the second series, the spikes were driven into their respective pieces of timber and then soaked for a few days in water. The pieces into which different spikes were driven, were as nearly alike as it was practicable to obtain them, being always cut from the same plank avoiding knots, cracks, &c. The following table contains a view of the experiments made after soaking the timber.

Table II.

Timber soaked after Spikes were driven.

No. of the experiments.	Kind of spike used.	Kind and condition of the timber.	Breadth of the spike.	Thickness of the spike.	Depth to which it was driven.	Weight in grains of the part inserted.	Force to extract the spike in lbs.	Ratio of extracting force to weight of spike.	Date.	Remarks.
			inch.	inch.	inch.					
1	Swelled and grooved.	Chestnut unseasoned	.375	.300	3.5	806	1710	2.121	Dec. 3, 1835	In this and the four following experiments the thickness of the spike is that found at the bottom or hollows of the grooves.
2	Do.	Yellow pine seasoned.	.375	.300	3.5	806	1668	2.069	Do.	
3	Do.	Hemlock partly seasoned.	.375	.300	3.5	806	1738	2.156	Do.	
4	Do.	White oak seasoned.	.375	.300	3.5	806	3373	4.184	Do.	The oak used in this exp'nt was firmer than that employed in the first series.
5	Do.	Locust partly seasoned.	.375	.300	3.5	806	4902	6.081	Do.	The timber had been slightly split by driving.
6	With the swell filed away.	Unseasoned chestnut	.390	.300	3.5	759	1852.5	2.440	Do.	The flanches remained after filing out the swelled part of the original form.
7	Do.	Seasoned yel. pine.	.390	.300	3.5	759	1767	2.328	Do.	
8	Do.	Hemlock partly seasoned.	.390	.300	3.5	759	1296.8	1.576	Do.	
9	Plain spike draw filed lengthwise.	Chetnut unseasoned	.400	.394	3.625	933.5	1790	1.810	Do.	
10	Do.	Hemlock partly seasoned.	.400	.394	3.5	933.5	1638.75	1.755	Do.	
11	Do.	Locust partly seasoned.	.400	.394	3.5	933.5	3990	4.167	Do.	
12	Do.	Do.	.400	.394	3.5	933.5	4332	4.640	Do.	Timber slightly split in driving the spike.
13	Grooved & notched or serrated.	White oak.	.392	.315	3.625	759	2622	3.454	Do.	
14	Burden's patent.	Do.	.339	.329	3.625	639	2152	3.367	Do.	

The first five of the preceding experiments show that with a spike of given form, and driven a certain distance into different timbers the order of retentiveness beginning with the highest is, as follows: 1. Locust; 2. White Oak; 3. Hemlock; 4. Unseasoned Chestnut; 5. Yellow Pine.

From the 6th, 7th and 8th experiments, we see that chestnut is still above yellow pine, but that hemlock is inferior to both. By the 9th and 10th, it also appears that hemlock is still to be placed below chestnut. Comparing the first experiment in this table with the 6th, and the 2d with the 7th, we perceive that the swell towards the point of the grooved spike was so far from being an advantage to it, that it, in fact, rendered the spike less retentive than when that swelled part had been removed, so that even could this form have been produced without any increase in the weight of the spike, it would still have been less advantageous than the simple groove without the swell, but when it is considered that the swell added 47 grains (806—759), to the weight, it is evident that the groove alone has a decided advantage over the other form. By the trials in unseasoned chestnut (Nos. 1 and 6) this advantage is 15 per cent. thus $\frac{2440-2121}{2121}=15.$ and by those on yellow pine (Nos. 2 and 7) it is $\frac{2328-2069}{2069}=12.5$ per cent.

In fact, after the ends of the fibres have once been thrust apart by the thick part of the swell it is evident that when they come opposite to the cavity, above the swell, they must lose some part of their power to press the spike and to produce the retaining force of friction. This force must then depend for its production on the action of those fibres of the wood which are opposite to the swelled portion, or between it and the points of the spike.

In the next series of experiments it was attempted to ascertain the relation between forms more diversified than had hitherto been employed.

As it is evident that the total retentiveness of the wood must depend, in a considerable degree, upon the number of fibres which are longitudinally compressed by the spike, it was inferred that on the area of the two faces which, in driving the spike, are placed against the ends of the fibres, must in a great measure, depend the retention of the spike. In this series four kinds of wood and ten forms of spikes were employed.

A comparison of the results, given in the following table, will show what order these *forms* would possess among themselves, in point of retentiveness as well as the advantages of the respective species of timber into which they were severally driven.

Table III.

Spikes of various forms—Timber of different kinds.

No. of the exp'nt.	Kind of spike used.	Kind and condition of the timber used.	Breadth of spikes.	Thickness of spike.	Area of two faces.	Depth to which driven.	Weight of the part inserted.	Force to extract the spike.	Ratio of force to weight of spike.	Date.	Remarks.
			inc.	inc.	sq in	inc.	gr's.	lbs.		1835	
1	Straight square.	Chestnut unseasoned	.405	.402	2.83	3.5	942	1995	2.116	Dec. 4.	
2	Burden's patent.	Do.	.373	.384	2.64	3.5	866	1873	2.162	Dec. 8.	
3	Broad flat.	Do.	.539	.288	.377	3.5	898	2394	2.663	Dec. 4.	
4	Narrow flat.	Do.	.390	.253	2.73	3.5	566	2223	3.927	Dec. 8.	
5	Straight square.	White oak thoroughly seasoned.	.405	.402	2.83	3.5	942	3990	4 129	Dec. 7.	
6	Broad flat.	Do.	.539	.288	3.77	3.5	898	5130	5.712	Do.	
7	Narrow flat.	Do.	.390	.253	2.73	3.5	566	3990	7.049	Do.	
8	Burden's patent.	Do.	.373	.384	2.64	3.5	866	3905	4.509	Do.	
9	Cylindrical with cutting edge.	Do.	diam .485			3.5	1211	3876	3.200	Do.	
10	Grooved and swelled.	Do.	.375	.375	2.60	3.5	806	3727	4.624	Do.	The measures in this and the two following cases, taken outside of flanches.
11	Grooved but not swelled.	Do.	.375	.375	2.60	3.5	759	4247	5.662	Do.	
12	Grooved and bottoms of grooves serrated.	Do.	.375	.375	2.60	2.5	500	2650	5 300	Do.	The weight of part inserted is given by estimation in this experiment.
13	Square.	Locust seasoned for 3 years.	.405	.402	2.83	3.5	942	5967	6.334	Dec. 8.	
14	Broad flat.	Do.	.539	.288	3.77	3.5	898	7040	7.839	Do.	
15	Narrow flat.	Do.	.390	.253	2.73	3.5	566	5273	9.316	Do.	

Table III.—(Continued.)

No. of the exp'nt.	Kind of spike used.	Kind and condition of the timber used.	Breadth of spikes.	Thickness of spike.	Area of two faces.	Depth to which driven.	Weight of the part inserted.	Force to extract the spike.	Ratio of force to weight of spike.	Date	Remarks.
			inc.	inc.	sq in	inc.	gr's.	lbs.		1836	
16	Cylindrical pointed with 15 grooves filed longitudinally from the points upward.	Ash seasoned.	diam .500			3.5	929	2052	2.208	Jan. 4.	In this and the two following exp'nts the spikes were driven into the timber in the direction of the length of the fibres.
17	Do.	Do.	diam .500			3.5	929	2309	2.507	Do.	
18	Plain cylindrical pointed, scale not rem'd.	Do.	diam .500			3.5	1015	2451	2.414	Do.	

The above table furnishes three sets of comparisons for deducing the relative retentive powers of green chestnut, thoroughly seasoned oak, and equally seasoned locust. Thus the weight, which in those three cases drew the square spike from chestnut, was 1995 lbs. That which extracted the brood flat one, 2394, and that which drew the narrow flat one from the same timber, was 2223. The sum of these is 6612. The sum of the three numbers for the same three spikes used with oak, was, by experiments 5, 6, and 7, 13110; and the same of the three in locust, by experiments 13, 14, and 15 is 18280, these three numbers have to each other the relation of 1, 2, and $2\frac{3}{4}$, from which we infer that oak is almost precisely *twice*, and locust $2\frac{3}{4}$ times as tenacious as unseasoned chestnut. By comparing together the results of experiments 1 and 2, it will be seen that the weights required for extracting the two spikes respectively are more nearly proportional to the breadths than to either the thicknesses or the weights of the spikes, for the spike with a breadth of .405 inch, and a thickness of .402 required 1995 lbs. for its removal, while that which had a breadth of .375 inch, took 1873 lbs.

Now .373 : .405 : : 1873 : 2033 for the calculated retentiveness, instead of 1995 as given by experiment,—a difference of only + 38 lbs. between the observed and calculated results. Calculating the retention by the *weights* of the respective spikes, we should have 866 : 942 : : 1873 : 2037, or a difference of 42 lbs; while using the *thicknesses* alone, we obtain .384 . 402 : : 1873 : 1960, a difference of an opposite kind of 35 lbs. from the observed result. The greater thickness yielding the less retentive power. This correspondence between the breadths and the extracting weights, becomes still more apparent when we compare the *third* and especially the *fourth* with the *second* experiment. Thus for the broad flat spike (3d experiment) compared with experiment 2nd we have,

By breadths .373 : .539 : : 1873 : 2701 instead of 2394—diff. + 307
By weights .866 : .898 : : 1873 : 1942 - - " — 452
By thicknesses .384 : .288 : : 1873 : 1379 - " — 1015

And for the thinner and lighter spike (experiment 5th) compared with No. 2. we have,

By breadths .373 : .390 : : 1873 : 1958 instead of 2223 observed, dif — 265
By weights .866 : .566 : : 1873 : 1224 - - " — 999
By thickness .384 : .253 : : 1873 : 1234 - - " — 989

Nearly the same conclusions would result from a comparison of those trials which were made on seasoned white oak and locust. Indeed it appears, that with a given breadth on the face of the spike, a diminution of thickness is sometimes a positive advantage to the retentiveness of the timber, for on white oak the spike which had a breadth of only .390, required as much force to extract it, as one of which the breadth was .405—though the thickness of the former was but .253, while that of the latter was .402, and on chestnut the thinner, narrower and lighter spike required absolutely more force to withdraw it, than the other. This leads us to notice the different kinds of action of the respective spikes on timbers of various kinds.

In the softer and more spongy kinds of wood the fibres instead of being forced back longitudinally and condensed upon themselves, are by driving a thick, and especially a rather obtusely pointed, spike, folded in masses backward and downward so as to leave, in certain parts only, the faces of the grain of the timber, in contact with the surface of the metal.

That the view just presented is correct, seems also probable from what was observed in the case of the swelled spike. For while the grooved but *unswelled* one driven into chestnut timber (Table II. Ex. 6,) required 1852 lbs. to extract it, the grooved and swelled one (Ex. 1. same table,) took but 1710. And in table III. Ex. 2, we find the swelled spike drawn from white oak by 3727 lbs., and the grooved but not swelled one (Ex. 12,) requiring 4247. Hence, it appears to be necessary in order to obtain the greatest effect, that the fibres of the wood should press the faces as nearly as possible in their longitudinal direction, and with equal intensities throughout the whole length of the spike.

Arranging the spikes according to the order of their ratios of *retention* to *weight*, as given by the experiments from 5 to 12, inclusive, in Table III., we have the following:

1.	Narrow flat, with a ratio of	7.049
2.	Wide flat, - -	5.712
3.	Grooved but not swelled, -	5.662
4.	Grooved and notched, -	5.300
5.	Grooved and swelled, - -	4.624
6.	Burden's patent, - -	4.509
7.	Square hammered spike, -	4.129
8.	Plain cylindrical, - -	3.200

Experiments 16, 17, and 18 of the same table were made by driving the spikes, which were cylindrical with conical points into the timber endwise of the grain. This method of comparing two forms, the one grooved, and the other plain, was adopted on account of the extreme liability of the timber to be split by driving spikes of these forms across the direction of the fibres. It was observed that on drawing these spikes the holes were almost perfectly square. This resulted from the position of the rings of annual growth, and the greater elasticity in some directions than in others. It is probable that, if the filed grooves, in experiments 16 and 17, had been

covered with a scale of oxide, as was the case with the plain spike used in experiment 18, the former would have given a somewhat higher result. When holes are drilled into stone blocks and afterwards plugged with timber to receive spikes, in fastening on the chairs of edge rails, the method of experimenting just described finds an application, and it is probable that in such cases the grooved cylinder, with a conical grooved point, may prove advantageous.

A few experiments were made to determine the effect of driving spikes to different depths on the total amount of retention. For this purpose two different spikes were selected, viz: the square hand-wrought spike, the section of which was .405 × .402, and the wide flat one, of which the section was .539 × :288. They were respectively driven to a certain depth into unseasoned chestnut—and then subjected to force just sufficient to start them,—this force was noted, the spike was then driven another inch and the force applied in like manner. All my experiments proved that when a spike is once started, the force required for its final extraction is much less than that which produced the first movement. This is readily accounted for, on the principle that a wedge shaped point was from half an inch to an inch in length, and as this on the starting back of the spike a very little distance, became mostly relieved from the pressure of the fibres, all that part of the retention, which had been due to the wedged shape portion was at once destroyed. The following table will show that the mere starting of the spike, with parallel faces, does not essentially diminish the retention when again driven into the timber to a greater depth than before.

But when a bar of iron is spiked upon wood, if the spike be driven down until the bar compresses the wood to a great degree, the recoil of the latter may become so great as to start back the spike a short distance after the last blow has been given. In this case a great diminution in the useful effect will be the consequence. This shows that a limit may exist to the force which we should apply in urging down spikes or bolts, especially those with large heads, destined to fasten materials together.

Table IV.

Spikes driven to different depths.

No. of experiment.	Form of spike.	Kind and condition of timber.	Breadth of Spike.	Thickness of spike	Area of the faces.	Depth to which the spike was driven.	Weight of the part inserted.	Force to extract the spike.	Ratio of force to weight of spike.	Date.	Remarks.
			in.	n.	sq. in.	in.	grs.	lbs.		1835	
1	Square not filed.	Chestnut unseasoned.	.405	.402	.7695	1.9	483	1183	2.428	Dec. 4.	$\frac{\text{Retention}}{\text{area of faces}}=770$
2	Do.	Do.	Do.	Do.	1.1745	2.9	789	1995	2.528	Do.	Do. =850
3	Do.	Do.	Do.	Do.	.1579	3.9	1095	2565	2.342	Do.	Do. =795
4	Broad flat.	Do.	. 9	.288	.9702	1.8	442	1525	3.457	Do.	Do. =785
5	Do.	Do.	Do.	Do.	1.5092	2.8	745	2594	3.482	Do.	Do. =865
											Mean 813

By comparing experiments 1 and 4 together it will be found that *weight for weight*, the flat spike had, when driven 1.8 inches, an advantage of 42.3 per cent. over the square one; and by like comparison of experiments 2 and 5, it is evident the former had a superiority of 37.7 per cent. As the spike when driven in only 1.9 inches had a much less proportion of its parallel faces and a greater proportion of the wedge shaped point, exposed to the reaction of the fibres, it is reasonable to expect that the retention would not correspond precisely with the lengths inserted. It will be understood that when we speak of cutting edges and the wedge shaped portion of spikes, whether square, flat, or cylindrical, the direction of the cutting edges is always across the fibre or grain of the timber. It must be evident that the wedge shaped part may be so acute as to correspond nearly with two parallel faces, in which case, the tendency to retreat from the lateral pressures is small, and the pressures themselves increasing from the point upwards to where the spike is thickest, the total efficiency of a given length may be as great as that of an equal length of the parallel faces, and even greater provided the thickness of the spike be so great as in driving it to produce much crushing and irregular folding of the fibres of the timber. If, on the contrary, the edge be very blunt, the tendency to recoil may be such as to diminish the adhesion and in this case the effect of the wedge shape is negative. In the other it may be positive.* The 1st, 2d, and 3d experiments indicate, in the 10th column of the preceding table, that beyond a certain limit the ratio of weight of metal to extracting force begins to diminish, showing that it would be more economical to increase the number rather that the length of spikes for producing a given effect in fastening materials together. In this case also it will be perceived that the adhesion has a much closer relation to the areas of the compressing faces of the spikes than to their weights. The 12th column shows that for three of the experiments this ratio may be regarded as *identical*, and the whole set goes to prove that the absolute retaining power of unseasoned chestnut on square or flat spikes of from two to four inches in length, is a little more than 800 lbs. for every square inch of their two faces which condense longitudinally the fibres of the timber.

The accompanying figures represent the appearances of timber as developed by splitting the specimens, through the axis of the cavities, left by the spikes when withdrawn.

Fig. 1—Is that presented by the locust timber, mentioned in Table II., Experiment 11, in which the weight required to extract the spike was 3990 lbs. The upper part of the figure exhibits the rising up of the timber just as the spike starts. In every case this effect was found, on examining the timber, to have been of very limited extent.

Fig. 2—Represents the grain of chestnut timber as affected in experiment 3, Table III, with the broad flat spike, and other trials. At the point of inflection downward the grain appears to be not only bent but often actually broken off.

Fig. 3—Exhibits the appearance of a specimen of hemlock timber, used in experiment with the straight grooved spike, (Fig. 4 of spikes) in which the weight required to extract it was but 1296 lbs.—See Table II, Experiment 8th.

* The following formula may represent the several experiments $R=lf\pm c$ in which R is the observed retention; $l=$ the length in inches of the part inserted; $f=$ the force of retention on one inch of the parallel sides; and $c=$ the difference between the retention of a parallel portion of the spike and of an equal length of the converging faces near the point. The sign of ambiguity is due to the cause above stated.

1. 2. *Figures of Timber.* 3. 4.

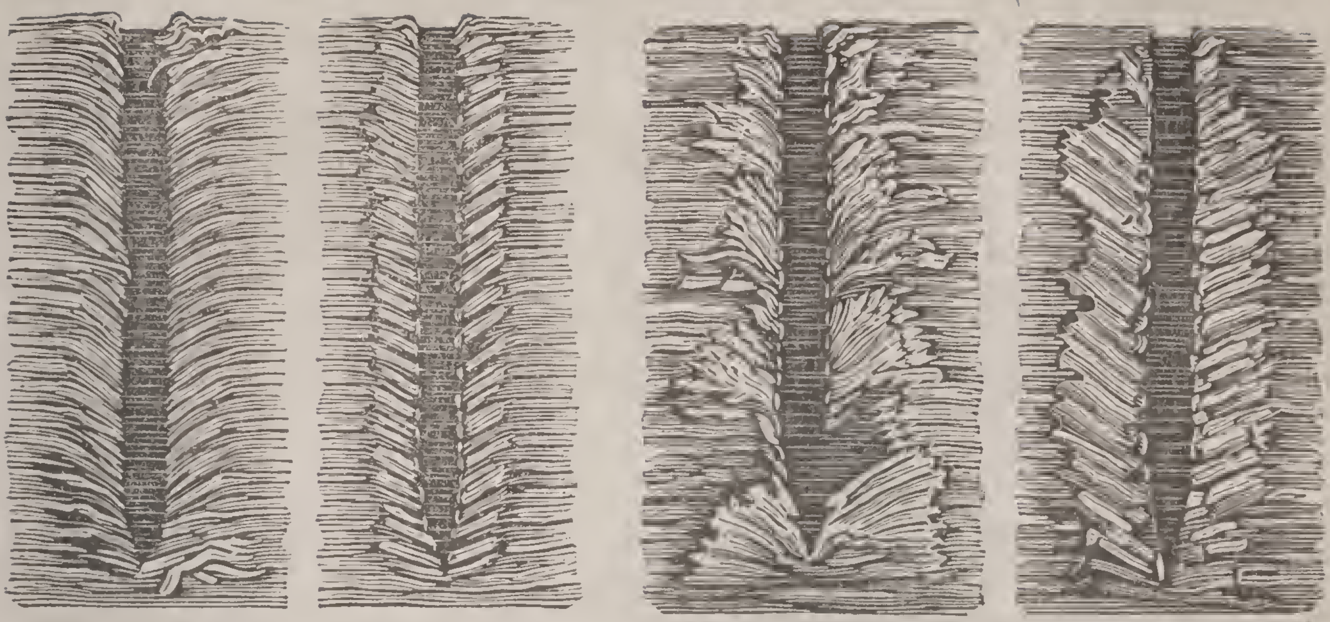


Fig. 4—Conveys an idea of the manner in which a defective specimen of pitch pine was affected by a spike. The force required to draw this spike was so trifling that it was not thought worth recording in the tables.

Figures of Spikes.

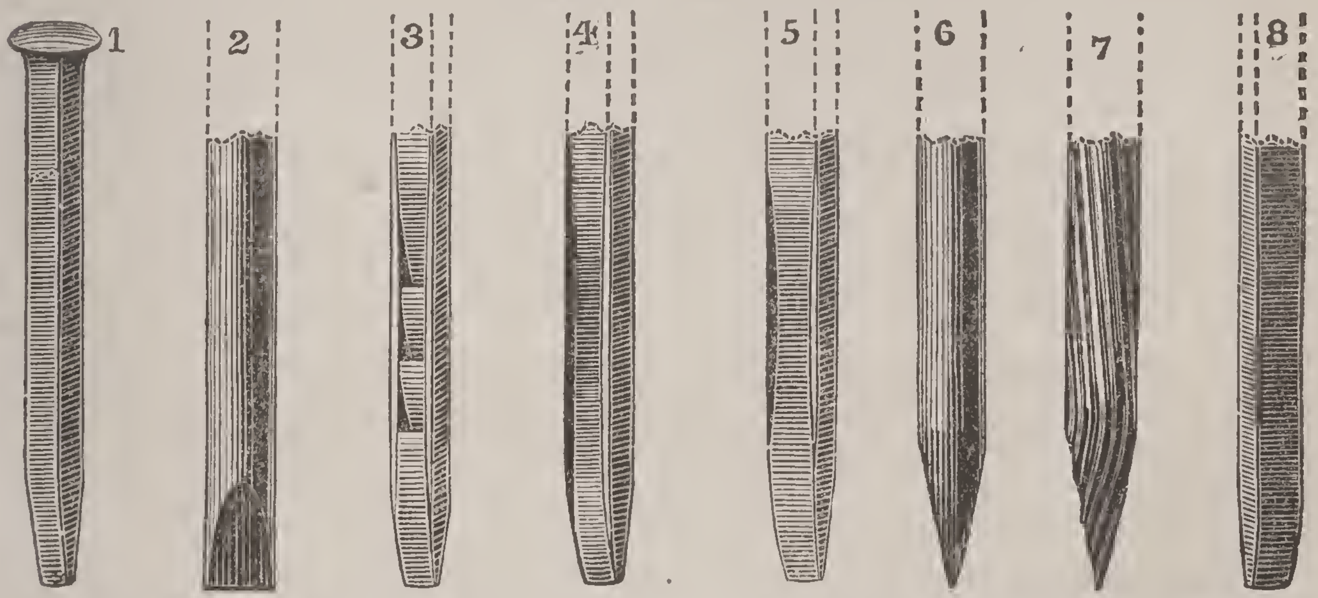


Fig. 1—is a square spike .405 of an inch wide on each face,—referred to in Table III, Experiments 1, 5, and 13.

Fig. 2—is a cylindrical spike .485 inch in diameter, sharpened to a cutting edge—see Table III, Experiment 9.

Fig. 3—is the grooved and notched spike, serrated in the bottoms of the grooves on the two faces, Table III, Experiment 12.

Fig. 4—is a spike with plain grooves on the faces, extending from the upper part of the bevel to the height of about 3½ inches.

Fig. 5—is a grooved and swelled spike, that is, having the groove deeper at the distance of two inches from the point, than it is at one inch from it. At the former the depth of each groove is .066 inch.

Fig. 6—is a cylindrical spike .5 inch in diameter, tapered to a point.

Fig. 7—is a spike of the same diameter as the preceding, but having 15 spiral grooves proceeding from the point upward.

Fig. 8—is a flat spike .390 inch in breadth, and .253 inch in thickness. See Table III, Experiments 4, 7, and 15.

Note.—The only series of experiments, analogous to those above detailed, which has fallen under the notice of the writer was made in 1824*, by Mr. B.

* See Gill's Technical Repository, vol. V., p. 248.

Bevan, on the adhesion of sprigs, brads and nails, when driven into timber longitudinally and transversely. His operations were extended to several kinds of timber, viz:—Norway deal, dry oak, elm, dry beech and green sycamore.

He employed some nails of a very minute size of which 4560 were required to make a pound avoirdupois. One of these required 22 lbs. to extract it, when driven .4 of an inch into pine board. From this size he advanced by several gradations to the sixpenny wrought nail, of which 73 make a pound avoirdupois. Of the latter he drove one to the depth of one inch successively into pine, elm, dry oak, dry beech, and green sycamore, and found the forces required for its extraction to be as follows:

For Pine,	187 lbs.	Beech,	667
Elm,	327	Sycamore,	312
Oak,	507		

Mr. Bevan examined, to some extent, the difference between driving a nail by percussion with a hammer of known weight and range of fall, and forcing it into the wood by simple pressure. This curious inquiry did not, for obvious reasons, enter into the plan of the writer of this article. Mr. B. found that to force a sixpenny nail into pine 1 inch, it took a pressure of 235 lbs.; to extract it, 187; to force it in $1\frac{1}{2}$ inch 400; to extract it 327;
" 2 inches 610; " 530.

Observations on the effects of a remarkable atmospheric current or Storm as witnessed on the day following its occurrence. By WALTER R. JOHNSON, A. M., Mem. Acad. Nat. Sci. of Philadelphia, &c.

Read Febuary, 21, 1837.*

CONSIDERED as a meteorological phenomenon, the calamity which, on the 19th of June 1835, desolated a part of the city of New-Brunswick

* The substance of these observations was verbally communicated to the Academy, June 23d, 1835—together with a diagram explanatory of the positions of trees prostrated, materials strewed upon the ground, and the situation of buildings, removed towards the centre of the track of the storm. The writer then took occasion to suggest that an examination of the forest land, passed over by the tornado, should be made by the help of the compass, in order to verify the justness of the views which he had presented, respecting the direction of the trees in different parts throughout the breadth of the track. This task was subsequently performed during a visit to the scene of devastation, by Messrs. ESPY and BACHE, the result of which showed conclusively the correctness of the general statements contained in this paper. The remarks in this article were prepared immediately after the communication to the Academy, and submitted to a friend, in whose hands they remained till within a few days of the time when they were read; which accounts for the delay in their presentation to the Academy, and has given time for the publication of several other accounts, the materials for which were afterwards collected.

in New-Jersey, is worthy of the most attentive investigation. In connexion with the accompanying sudden, and singular changes of temperature, and moisture in the air, it may serve to illustrate the causes of those occurrences which, sometimes in our own climate—and more frequently in tropical regions—display effects which have hitherto perplexed the minds of the most acute observers. All accounts concur in representing the air of the morning, and indeed of the whole day up to the time of the tornado, as unusually sultry. This was observed between the hours of two and four P. M., in a ride from Hightstown to Princeton, a distance of about nine miles; also, in the city of New-York, and on the voyage from the latter city to New-Brunswick. At four o'clock the sun was still unobscured at Princeton; but within half an hour a cloud from the north-west had reached that place, and a shower of rain, accompanied by a brisk wind from the south-west, had commenced. Before five o'clock, the rain had ceased, and the air was less oppressive. The evening continued tranquil until ten o'clock, when another shower of rain fell, accompanied by some wind; but within half an hour, the sky was once more cloudless, and the wind began to rise with much force, from the west or north-west. Some observations on Polaris, Saturn, and other hea-

venly bodies, were made by Mr. ALEXANDER of that place, between eleven and twelve o'clock, but the state of the air did not appear favourable to the distinct, and steady perception of the minuter telescopic objects; owing, as was supposed, to irregular refraction, and the occasional sudden formation of mist in certain quarters of the heavens. A sensible depression of the dew-point was noticed at the time as indicated by the action of the air on the lungs, as well as on the surface of the body. From 12 at night to 5 the next morning the wind was boisterous; and a great change in the state of the atmosphere had obviously taken place. An electrical machine, which it had on the day previous been found impossible to excite, was, at nine or ten o'clock, A. M., able to yield sparks an inch and a half or two inches long, between balls three-fourths of an inch in diameter—a sure indication of an increased distance between the dew-point and the temperature.

Intelligence of the occurrences at New-Brunswick having been received during the forenoon, it was resolved to visit the spot, and endeavour to ascertain, by observation and inquiry, while the traces were yet unobliterated, such facts as might explain the mode of action by which the devastation had been effected. On arriving within six miles of New-Brunswick, on the old turnpike

road, we* were informed by an eye-witness, that it had been seen about a mile and a half north-easterly from that point; and that the dense black cloud was, by the junior observers, conceived to be *filled with crows,* — an appearance, afterwards explained by the fact that shingles, boards, &c., had been carried upward by the tempest from buildings destroyed in that vicinity.

On reaching the height of land, at about half a mile from the dense portion of the city, the first buildings which had been damaged by the tornado were passed. A barn had been completely demolished, and most of the lighter materials scattered to a great distance. The house was not thrown down, but left leaning with no part of the roof remaining, except some of the rafters; and the fact here witnessed was repeatedly observed in the town below, where several houses within the path of the tornado were deprived of their shingles, and the ribs which had held them to the rafters; but the latter still continued partially or entirely undisturbed. In a few cases, in which the ridge of a building lay in a northerly and southerly position, the eastern slope of roof was

* In this excursion, and the subsequent inquiries, the writer was accompanied, and aided by his friend Professor Joseph Henry; who is to be considered as entitled to a full share of whatever credit may attach to the observations referred to in this paper.

observed to be removed, or at least stripped of its shingles, while the western slope remained entire. Many buildings were likewise observed with holes in their roofs, whether shingled or tiled, but otherwise not much damaged, unless by the demolition of windows. These appearances clearly demonstrated the strong *upward* tendency of the forces by which they were produced, while the half unroofed houses, already mentioned, prove that the resultant of all the forces in action at the moment was not in a perpendicular to the horizon, but inclined to the east. Such a force would apply to the western slope of the roof some counteracting tendency, or relieve it from some portion of the upward pressure. Had there been no other facts to show the powerful rushing of currents upward, the above would, it is conceived, have been sufficient to settle the question, but taken in connexion with the circumstance that roofs so removed, were carried to a great height and their fragments distributed over a large extent along the subsequent path of the storm, that beds and other furniture were taken out of the upper stories of unroofed houses, that persons were lifted from their feet or dashed *upward* against walls; and that in one instance, a lad of eight or nine years old, was carried upward and onward with the wind, a distance of several hundred yards; and particularly that

he afterwards descended in safety, being prevented from a violent fall by the upward forces, within the range of which he still continued :—in connexion with these and similar facts, it seems impossible to doubt that the greatest violence of action was in an upward and easterly direction.

The next point to which attention was called by the appearances around, was the manner in which this upward current had been supplied from below; and for the solution of this question, it was necessary to compare objects throughout the whole breadth of the track left by the storm. A peach orchard on the slope of the hill descending to the town gave the first indication in regard to this matter, but the larger fruit and ornamental trees, in the gardens of Dr. Janeway, Messrs. Kikpatrick and others, in the same neighbourhood, together with an inspection of the forest on the east side of the river, showed conclusively that on the extreme borders of the track the forces were nearly, or quite at right angles to its general direction. Uprooted trees along the southern border lay with their tops towards the north; those on the northern border to the south, thus pointing to a common object in the central line of the current. From the outer edges however toward this central line the trees were observed on both sides to have a gradually increasing inclination to-

wards the east, and in the middle to be entirely in *that,* as a general direction. I do not recollect to have encountered a single case in which the top of a tree *with its roots in the ground* was lying towards the west, though I cannot say that none occurred, for among the houses and other obstacles within the city, presenting different degrees of resistance to the lateral currents, there may very probably be some points in which great violence was exerted in directions varying from the general course of action. None were seen with the tops from the centre of the path. Another fact to this point, is, that Dr. JANEWAY's barn, a frame building, which was on the southrely part of the track, was unroofed, and the remaining part of the structure with its contents removed bodily three or four feet to the *northward.* All the herbage, shrubs and trees in its immediate vicinity, and the trees of KIRKPATRICK's garden, were found lying with their heads in a northerly or northeasterly direction. Similar to the case of the barn just mentioned was that of BISHOP's store, near the river; which, standing on the northern border, had been lifted from its foundation about four or five feet towards the south. A row of poplar trees which had been prostrated in the lower part of the city,

and on the *northern* part of the path was observed as a striking exemplification of the application of lateral force, every tree taking in its fall a southerly direction. Another evidence of lateral inward currents, was found in the appearance of many forest trees, east of the river, which though too far removed from the central line of the path to be uprooted, were still so much within the range of the lateral forces as to have their outside limbs, or those most remote from the central line, broken off by the effect of cross strain; while no similar fracture was seen on limbs turned towards the centre of the path. This result will be easily understood, when we consider the well known difference between breaking a limb by cross strain and that of drawing it asunder by simple longitudinal tension.

Another fact indicative of the direction of currents from the sides inward, was noticed on the plain east of the Raritan, where the fragments of boards, shingles, ribs, &c., which had been brought from houses demolished in the city, were seen to be arranged on the ground with some irregularity, certainly, but with far greater conformity of position than we could have anticipated. Their longitudinal direction was generally towards the central line, and also towards the point to

which the storm was moving. Many of these were found far beyond the belt of ground on which the violence of the wind had been exerted. Their position may be explained by referring to the three forces in action at the moment they reached the ground:—first, the force of gravity, which, if the air had been motionless, and the bodies descending perpendicularly, would probably—from the unequal density of the parts of the several masses—have caused most of them to descend endwise; and then the position, subsequently taken by them respectively, would have been a matter of indifference, and we might have expected to find them lying promiscuously. But, second, they were, while in the air, moving onward with the storm in an easterly direction and when the lower end struck the ground, the composition of this force with gravity, would naturally have thrown the centre of gravity over to the *east*, and we should have expected to find the lighter end of every piece of timber in that direction. But, third, if a current of wind were encountered near the ground, running towards the centre of the path, we should, on the north side of the path, expect to find the lighter ends of each piece directed to the southeast, and on the south side, to the northeast; precisely what appeared to be the case, so far as

could be judged from the general appearance of the masses.

The next set of facts observed, was that which relates to the course of the materials projected upwards after they had arrived at a considerable elevation. All accounts agree that the appearance of the cloud was that of a funnel or inverted cone with the apex resting on the ground. The falling rafters, scantlings, and other parts of the ruined buildings, generally indicated that they were, subsequently to the *upward* violent action, carried outward by the gradual enlargement of the current into which they had been drawn. The shingles and boards, just described, were cases in point being found far beyond the trail of the tornado as marked upon the surface. Rafters, which penetrated buildings south of the track, entered them on the north side and in a direction inclining to the southeast. Their descent in some instances was with great violence, contrary to what happened in the range of the upward motions; where a lad, already referred to, was deposited in safety after an aërial journey of one-fourth of a mile. A window frame and brick wall were, in one instance, penetrated by a rafter, twenty feet in length, eight inches wide, and from four to six inches thick. In the passage of the storm from the city

to the opposite bank of the Raritan, no indications are, of course, left to mark the peculiar action upon the waters; though we have heard it stated, but cannot say upon what authority, that the bed of the channel was laid bare, and from the nature of the forces and their violence, we cannot doubt that had it traversed a great extent of water surface, it would have assumed the character, as it certainly had the *form*, of a water spout. On encountering, however, the opposite bank, some peculiar effects were seen to have been produced. The upper edge of the bank especially, was marked by two well defined stripes, each from ten to twenty feet wide, and one hundred, or more, feet asunder. Here, it was supposed, must have been the outer edge of the aërial trunk, or funnel through which the air rushed upwards, and as the tornado, in its onward movement, advanced against the bank, the air coming in on every side to fill up the partial vacuum would exert the greatest force at the moment when it changed its horizontal for a vertical motion. The surface of the ground beyond this point seemed, in some places, to have been raised, as if the air beneath, by its sudden rarefaction, had thrown up small portions of the soil which was rather dry and porous; and it is, perhaps, worth consideration, whether this cause

may not, in this and similar occurrences, have facilitated the overturning of trees themselves.

It was a subject of regret at the moment, that want of time, and of a suitable instrument to measure the exact course of the tornado, and the precise position of trees in the different parts of the track, prevented carrying out a plan, which suggested itself on the spot, as the most satisfactory method of arriving at precision on those points.

In conclusion it may be remarked, that the directions and intensities of the forces in this occurrence, together with the hygrometric states of the air, preceding and following the meteor, and the inverted conical form of the moving column, as confirmed by several witnesses, not less than the fall of hail, and the distribution of fragments of materials beyond the path of the ground current —seem most satisfactorily accounted for, on the supposition that a disturbance of atmospheric equilibrium, results from a deposition of moisture in the higher regions of the atmosphere giving out a great amount of latent heat, which, in turn, expands the cold dry air above the forming cloud, and creates an ascending movement; the expansion of pure air by an addition of heat, being in such cases much greater than the contraction of the

atmospheric mixture by a condensation of its moisture.—In this effect is, of course, involved the well known principle that the capacity of air for heat is augmented as its volume expands, but the increase of capacity for heat being less rapid than the supply of heat from aqueous depositions, an ascending current is maintained with a force due to the difference of these two causes.*

* The origin of this view of the subject with which the writer had been made acquainted previously to the examination above detailed, is due to Mr. J. P. Espy.

ON

SCHOOLS OF THE ARTS.

R. –

BY W. JOHNSON.

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SCHOOLS OF THE ARTS.

Among numerous causes which contribute to the welfare of our species, considered in the aggregate, few can be mentioned more deeply interesting, than the productive industry of nations.

While war was the chief occupation, and rapine the frequent amusement of those who boasted themselves the chiefs of mankind, it can hardly be considered surprising that the industrious, of all classes, should be little regarded, or if heeded at all should be mainly employed as the servile ministers to pride, avarice, lust or ambition.

It was not until the course of events had in some measure opened the eyes of mankind to the folly of attributing to martial exploits all the glory which human beings can possibly attain, to the glowing absurdity of investing the mere soldier of fortune with supreme control over the lives and the destinies of his fellow beings, and to the monstrous injustice of placing those who essentially support and adorn society, in a degraded rank with respect to the other classes of their fellow men ; — it was not until these truths had gained some ascendency over the prejudices of the world, that it began to be a matter of grave deliberation, how the interests of the industrious classes could be effectually served ; — how the tiller of the soil, the tenant of the workshop, and the traverser of the ocean, could be secured, each in the possession of those fruits of his labors, which, all confessed, were most richly merited.

It is true that long before any such estimate of the value of industry had been distinctly avowed, and long before the science of political economy had assumed a rank

among her sisters, there was an abundance of legislative enactments, or of arbitrary edicts, touching the industrious callings. But these were commonly designed to promote the temporary aims of governments, and would never have been enacted for the mere purpose of advancing the happiness of the artizan as an important member of the body politic.

Nor would the convenience, the interest, or the wishes, of a great majority of a nation have proved an adequate motive to induce the rulers of past generations to encourage the labors of industry.

The question with them was, how can the sinews of war, and the means of regal aggrandizement be most plausibly and with the least resistance, extracted from the hands of industry and thrust into the royal coffers?

Each monarch, and each of his ministers, answered the question according to the dictates of his own ingenuity, subtilty, wants or fears ; and hence the diversity of schemes and measures for raising revenue or for securing adherents among the *useful* classes ; — *useful* according to the political use which could be made of them. The artizan was accordingly subjected to perpetual fluctuations in the condition and circumstances of his life ; — today, courted, flattered and patronized, — tomorrow, neglected, contemned and oppressed with exactions. Now, invited to quit the land of his nativity in order to enjoy more of the sunshine of royal favor in a foreign realm — then by the operation of tyrannical edicts compelled to abandon his home and seek an asylum among strangers, to create perchance after years of privation, a new demand for the products of his skill.

But these things have given place within the last century to a state of affairs far more propitious to the general interests of society, more grateful to the feelings of the industrious, and more strictly in accordance with the natural sense of justice than any which had preceded.

Wherever civilization prevails, — wherever the popular mind has freed itself from the bonds of prejudice, there we shall find the importance and the activity of the arts daily increasing.

Checked, perhaps, and occasionally paralyzed by the ignorance of those who affect to be their guardians or by

the obstinacy of those who refuse their just claims to respect, still their vigor is unabated — their march firm and ever onward.

Divided and distracted on other questions, — pouring out, perchance, anathemas on each other's political or religious opinions, — men still very generally agree to adopt and to continue the use of all the substantial physical conveniences of which science, art and fortune will enable each to avail himself. And we need not go far to search for the cause of this unanimity. Every individual has the same reason for it, and he can state his reason in five words, — "*I prefer comfort to discomfort.*"

But what evidence have we, that the prevalent activity in the arts has really improved the human condition?

To furnish a perfectly unexceptionable reply to this inquiry it would be necessary to enter into a detailed comparison of the circumstances under which various classes of society have in different ages been found existing; to show how, they are now relatively above the condition of their ancestors and how many of the superior incidents of their present state are due to the modern advancements in useful arts. We may venture to predict, that such an investigation would end in a conviction, that the private citizen, possessing a tolerable competency in our day, has at his command infinitely more of the truly good things of life, than could possibly have been procured by the nobles and dignitaries of other days.

Take into view the food, the clothing, the habitations of men; the healthiness, the longevity, the intelligence of whole communities; witness the unfrequency in our times of famines and their direful consequences; the improvement, even in old and long cultivated countries, in the productiveness of those very soils which once yielded but a scanty pittance; the facilities of transportation, which enhance immeasurably the value of every production of art and labor, and the multitude of positive pleasures, before unknown to the human race, which are now added to the value of existence by the conquests of intellect over material things. Bring into the account, the intimate connexion between improvement in the useful arts, and every other kind of advancement in society, and add, if you please, the fact (of which I will not detain you with the proof,) that

the reign of the useful arts is the reign of common sense, and further, that the freedom and encouragement enjoyed by these arts, is, in every nation, the measure or exponent of that nation's freedom in every other particular. It is not meant to assert that the most absolute and the most arbitrary despot may not occasionally offer what he may call encouragement to the useful arts. But then it is merely the deceitful lure of patronage, a thing which, when coming from such a quarter, is found to insult as often as it protects the object of its care. This is not an occasion for tracing minutely the line of distinction between the ancient and the modern policy for encouraging the arts, or promoting inventive genius. Suffice it to say, that among the means of effecting these ends, due solely to modern times, is the plan of founding institutions expressly intended for instruction in practical science. You need not be informed that the institutions of learning existing previous to the time of establishing the modern schools of art, whether they professed to convey instruction to the young or to exercise the talents of the mature in age, were far remote from that practical usefulness which the state of society demanded. Not only had their pursuits no direct connexion with the useful arts, but those who were formed by their studies and discipline generally, regarded all contact with artizans and their vocations, as a species of contamination, most devoutly to be shunned. To be suspected of a design to turn one's knowledge of abstract or of physical science to practical account, was deemed next to the sordid meanness of the felon or the traitor; — and many a senseless sneer has been uttered against those who by word or action manifested that they preferred a fund of useful knowledge to the vaunted discipline of scholastic logic and casuistical or metaphysical learning. This state of things could not, however, be perpetual; the increasing lights which science, imperfectly applied, had shed upon the condition of social life, prepared the way for the more perfect philosophical day. When the darkness and oppression of the middle ages had past, and men had begun to return to sound reason, after the senseless and protracted wars of the crusades, they felt in all its atrocity the cruelty of that fanaticism which had sacrificed so many millions of human beings, and entailed misery on so many additional

millions, in a cause, in which the great mass of society had no actual or conceivable interest.

Again, after that peculiar organization of society, which grew out of the crusades, — I mean the feudal system, — had for a few hundred years exercised its tyrannical influence on the lives and fortunes of mankind, they began to perceive that human happiness was not the end and aim of their toils, their prowess, and their sufferings. They felt that pride of soul and arrogant pretension, were allowed to reap the fruit of honest industry; while the true benefactors of society, were commonly ground to the dust, by all the devices which selfishness and despotism could invent. Since the eyes of civilized nations have thus, within the last half century, been opened to the true distinction of merit, there has been less apparent disposition to cultivate national antipathies and to promote wars of conquest. This age has been distinguished by a pacific spirit, and, of course, by the cultivation of those arts which render the state of peace glorious and happy.

In like manner, when it became apparent, from the developements of philosophy, that the beneficent provisions of nature for the comfort and well being of man, were but partially understood and appreciated, — when it was felt that they who toiled in the useful arts, were in no degree valued or compensated according to the intrinsic importance of their services to mankind, — when men became alive to the fact, that the soldier of fortune, though perhaps a worthless man, was often extolled, caressed, and deified, while the most powerful intellect, the most pure morality, the most devoted patriotism, the most admirable skill and patient industry, were allowed to languish in obscurity, — they naturally sought the means of correcting to some extent this glaring injustice in the allotments of society. From this consideration and from a laudable zeal to build up the character of their age and nation on a more enduring basis, than had hitherto been laid, the friends of human happiness, devised the plan of diffusive instruction, and mutual co-operation in the enlargement of intellectual resources, among the industrious classes of society.

To perceive the important bearing of a union of efforts thus directed, we may refer to the analogous but more extensive operation of learned men to promote the cultivation

of science. The difference will be, that while schools of art are of limited extent, and are local in their nature, the scientific association is capable of embracing whole nations, or entire continents.

The cultivators of science, seem to have arrived at the conclusion, that the ancient organization of societies, can no longer carry forward the glorious ensigns of their cause. Personal prejudices and predilections are not found to be fit counterpoises to talent and moral worth. Those who have no philosophical importance are not now believed to be the best judges of scientific merit; those who, in the character of parasites, clung closest to *men*, are not in these days deemed the most respectable orders of creation; and the high grounds of science are not thought to be the most suitable arenas, into which pigmies should be brought to exhibit their puny dexterity. Men who value knowledge aright, cannot consent that her resources should be wasted, or her honors monopolized, by the weak who cannot, or by the indolent who will not, put forth an arm to sustain her character.

They are accordingly forming, or rather executing larger, more liberal, and, we may add, more republican plans of promoting the interests of truth.

In Germany, Great Britain, and more recently, in France, voluntary associations have annually convened, bearing to science the same relation, which this Institute bears to education, to deliberate on the condition and prospects of philosophy, and to devise means for its more effectual and systematic cultivation. A natural result of these united labors, is a clearer comprehension of the whole ground of scientific inquiry, frequent luminous surveys of its distinct fields, a facility of collecting the valuable results of all current investigations, and the exposition of points towards which observation and experiment still require to be directed, or to which mathematical analysis may be profitably applied. An incidental result of such extended associations, is the division of labor which it introduces into the operations of the active experimenters, the *working-men* of science. The efforts of many a mind have been paralyzed by the fact that no kindred spirits were at hand to cheer it onward amid toilsome efforts in its peculiar province, to rejoice in its success, or sympathize in its dis-

appointments. The peculiar nature of its pursuits did not harmonize with the prevalent habits of those in its immediate neighborhood, and it was compelled either to forego the advantage of a social feeling, or to fall into pursuits uncongenial to its nature.

But since a general understanding among the cultivators of the same branch or subdivision of science has been established, the most remote and solitary toils of every votary will find their appropriate stimulus, in the consciousness that a point of union can soon be found, to which the acquisition made, may at once be carried, with the certainty of being greeted with honor and reward. And even if the narrow and grovelling spirit of envy should seek to excite local, personal jealousies against the man of true merit; if petty meanness strive to wrest from the deserving the credit of their own labors, or to throw doubt and distrust around the lights of truth and justice, still will the noble efforts of genius be unremitted; still will the certainty of a tribunal superior to the influences of detraction, impel it to useful labor, and secure to mankind the results of its exertions. So, too, do schools and associations for promoting the arts, afford centres of action, towards which the ingenuity of the artizan may direct its energy and find a reciprocation of sentiments, or a communication of light for the guidance of its efforts. We may indeed regard these two contemporary forms of society, the one for advancing general science and the other for promoting the arts which depend upon its principles, to be most happily conjoined for mutual benefit.

So intimate is the connexion between the improvement in arts and the cultivation of physical science, that we shall in many cases find it impossible to separate the consideration of an art from that of the science of which it may have been either the offspring or the parent. In admitting, however, that science has often owed its very birth to the arts, we mean, of course, nothing more than that the latter have discovered by practice, particular truths, which the former has afterwards, by direct experiment, by analysis, and by general reasoning, converted into comprehensive laws to regulate future practice. The truth seems to be, that art has in such cases obeyed laws of nature, before science had discovered or announced their existence; but, to convert this fact into an argument against the utility of study-

ing the sciences, is, in reality, no less than to assert that it were better to owe all our principles of action to accidental discoveries, rather than to take them ready formed from the hands of philosophy.

While the wants of society are few in number, and the habits of men fixed, the means of gratifying the former and of sustaining the latter, are alike simple. In this state of things, the provision of any peculiar instruction, adapted to qualify particular individuals or classes for the prosecution of refinements in art, would be doubtless looked upon as chimerical. The establishment of a school for shepherds, an academy for fishermen, or an institute for hunters, would be little less than ridiculous; and were all society in this primitive state, or were there any, the remotest, probability that such would soon be its condition, we should think the time required to compose a discourse on such a theme, very unprofitably employed. Laying aside, however, every idea that the dreams of those social reformers, who found their expectations on a supposed retrograde movement in human affairs, we will assume the actual and probable condition of society, as the basis of our observations, and will endeavor to demonstrate the necessity for schools of the arts, — we will next ask your attention to the history of those establishments which have been erected for this purpose, — and endeavor to delineate their character, objects and effects.

That schools appropriated to the *arts*, (by which we intend at present to designate the *useful* arts,) those which depend on a knowledge and application of science, are *necessary*, will be abundantly evident when we consider how intimately the arts in question are interwoven with the great plans of social organization, and how closely the very well-being of society is allied to the successful prosecution of those arts to which science is peculiarly applicable. If, indeed, all the arts were simple handicrafts, we might send those who aspired to eminence in any one of them, to the workshop of the artizan, and bid them glean from the routine of manual labor, all the skill which their sanguine wishes may have prompted them to expect. And, if in the course of events, the art which had been learned were never destined to undergo a change, the trade acquired would be a permanent acquisition, liable only to the vicissitudes which affect all the great interests of mankind. But is this

a true picture of the useful arts? Is there any important department of them in which, to insure success, some degree of general science is not at this day demanded?

Is it true, that no progress is made, no new facilities acquired, which all, who would successfully prosecute their labors, must adopt, or else be content to see others outstripping them in the extent and profits of their industry? Is it true that the possession of principles of science has nothing to do with this self-adaptation to new and varying circumstances? Or is it not, on the contrary, *undeniably* true, that he only can be pronounced certainly secure of his gains, who not only has skill in his *hand*, but the seeds of other forms of skill in his *head!* But personal thrift seldom needs more than its own stimulants, and this is the lowest motive which should impel us to encourage the dissemination of those sciences which belong to the useful arts. In the desire to establish the full dominion of man over the physical creation, to place the citizens of our country in possession of all the blessings which nature has scattered around them, to overcome the natural obstacles which impede the free intercourse of the different parts of our extended country, to make known the treasures of the forest, the field, the river and the ocean, — to bring from the deep caverns of the mine, the wealth of our exhaustless mineral stores, and the no less gratifying facts of geological science, — these, become in the mind of the patriot and the philanthropist, motives of higher and nobler energy. But laying even these inducements for a moment out of the question, let us contemplate the case as between ourselves and other nations, not in a commercial, but a domestic point of view. Our admirable constitution, in its liberal dispensation of the blessings of freedom, and of free government, has allowed full liberty to foreigners of every name to prosecute among us their several plans of industry and of profit. The natural riches of our country are fully understood abroad; and among the nations of Europe, schools of art have been so long and so effectually applied to the purposes of individual and national improvement, that the success of well instructed artizans and directors of works, emigrating to this country is no longer a matter of doubt. *They* will, therefore, prepare if *we* do not, to take advantage of the bounty of nature; and when we find for-

eigners alone, with foreign capital, and foreign labor, in effect monopolizing the mines, the public improvements, nay, the very highways and water courses of our country, we may thank our own supineness for the deprivation which we shall suffer. To prove that this view of the case is not fanciful, let us cast a glance at the operations undertaken on our own soil. We shall find not a few of our gold, iron, and coal mines, and divers extensive manufacturing establishments, directed and controlled, if not entirely owned by foreigners. This is said with no desire to create or awaken an undue jealousy towards those enterprising individuals, who have sought our shores, with the purpose of reaping a share in that harvest of good which is spread out before the eye of intelligence and industry. We would use the fact as a motive for self-defence against the future degradation of native talent, and the entire appropriation by other than American citizens, of the richest fruits of enterprise. And how shall this self-defence be effected? Certainly, by no other means than those of fair and honorable competition, by well instructed artizans and men of practical science. And who does not know that such men are to be formed only by a peculiar course of discipline and instruction, and only with certainty, in *places* of instruction adapted to such purposes. That other places of education do not, except incidentally, effect the object, is not at all surprising, when we consider that they were mainly intended for other purposes, — for purposes which they are generally believed to fulfil. It is no reproach to a school of medicine, that it does not form lawyers, and perhaps none to a school of theology that it seldom or never sends forth good statesmen. Neither would we charge it as a dereliction of duty upon a "school of the prophets," whether legal, theological, medical, or political, that it only by a rare combination of accidents, becomes the foster parent of a thorough mechanist, a skilful engineer, a successful miner, a good manufacturing chemist, a discriminating assayer, an able architect, a profound metallurgist, or even a productive working-man in science. But with all these useful classes, the establishments of practical science in Europe, will supply our country if she do not supply herself. And the question is only in what manner, and by what means and appliances, shall the objects of a domestic supply be effected?

But we have other and urgent reasons, why institutions of the nature which we have indicated, ought to be established and fostered in our republic. And granting that even the guarantee of national independence, did not require that the useful arts should be fostered and protected among us, (a point which we are not now going to discuss), is there nothing in our feelings, as men and citizens, which should impel us to wish for their continued success? Is there nothing, for example, of mortified pride, in the fact, that on the very thoroughfares of our internal commerce, in their latest, most approved form, nearly the whole superior structure, is the product of foreign art? Are we not chagrined at the fact, that having gone to foreign lands to borrow capital, we are compelled to send it back to foreign artizans to procure the very materials over which the merchandize is to be transported, that must repay the debts we have contracted; and that these materials are for hundreds of miles in extent laid upon the surface over beds of the same ore of unsurpassed richness, accompanied by all the means required for their developement and preparation, and only lying unheeded through the want of skill and enterprise to bring them to a useful form; and must we be compelled to witness the moving agents, too, wrought by the hands of strangers, and inferior to what might be produced among ourselves, vaporing away over our meek dependence, bearing along the gorgeous trains, and belching forth their scorn at our want of self-respect, and of patriotic pride? Such things are in a thousand forms displaying themselves before us, if we will but open our eyes to their existence, and not wink in collusion at the national discredit which they imply.

Our remarks thus far, have been confined to the effect of schools of art, upon the arts themselves. As to their effect upon the artizans in elevating their character, preparing them for the successful prosecution not only of their respective callings but also of all the duties of citizens, we cannot for a moment entertain a doubt. Awaken and employ and strengthen one practical talent, and you have done more towards making a good citizen than if you had, without producing this result, stored his mind or his *imagination* with all the lore of a hundred ages. A school of arts, then, should seem to be no less important in a civil-

ized community than one for literature or abstract science. That this is not the opinion of one or of a few individuals the progress which they have already made will sufficiently testify.

We have stated some of the general historical facts connected with the originating of schools and institutions for the purposes of which we have been speaking. If we would know to what period their foundation is to be referred we need not perhaps go further back than the last quarter of the eighteenth century. Whatever institutions had before that period been devoted to the sciences, had generally copied with more or less precision the ancient character, and had deviated but little from the usages of past centuries.

From the moment when France, rising amidst a fearful convulsion from beneath that load of oppression under which she had so long groaned, began to cast about a scrutinizing glance at the causes which had paralyzed her industry and cramped her resources, she found that a want of general information in regard to the actual character of her mineral treasures, and to the processes, and methods to be adopted in mining operations had made her in a great measure dependent on Sweden, Russia and other nations for the supply of one of the most indispensable articles of general consumption; and this too while iron ore abounded in her own soil, where wood, coal, and all the means for its reduction were in the utmost plenty. In short, she was then in almost precisely the same situation with regard to this product of industry, as that in which we stand at this day. It was from a view of this particular case, that intelligent men in France determined on the establishment of an institution expressly devoted to those practical sciences which concern the art of mining. Hence originated the celebrated school of mines which by means of its instructions, its collections, the productions of its laboratories, and the extensive circulation of its journal, has done so much for improvement in that branch of art. The establishment was made a national concern, for the obvious reasons that the interest it sought to promote was national interest.

The impulse for establishing schools of art thus given, was extended to various other subjects, and resulted in the formation of the Polytechnic school, so much cherished by

Napoleon, and which has given to France so many able men distinguished alike in war and in peace, in art and in science. Into Great Britain the spirit of practical scientific instruction, was introduced in 1796, by Dr Anderson, in the foundation of a class for practical men and in the provision of means for supporting a distinct institution devoted to the interests of mechanics. From this model have been formed innumerable societies and institutions for subserving the general purpose of the arts. Instead however of receiving any very efficient support from the constituted authorities, they were in general left to the voluntary exertions of those who chose to enrol themselves as members, and sustain their share in the burthen of their maintenance. This has subjected them to some serious inconveniences. Though enjoying the vigor of popular institutions they have also occasionally felt the uncertainty of a reliance on a mere *subscription list*, for carrying into effect the useful plans which they had contemplated. They have also been subject to the pernicious influence of a disposition to narrow the limits of their usefulness by persons who having no regard for the real interests of the artizan, have apparently sought to mix in their affairs only to restrain their efforts, limit their instructions to a few paltry objects, or to derive from them some support to other institutions, which wanting a popular character, wanted also the favor of the public.

The rapid multiplication of societies for the purposes of popular instruction, in England, France, Belgium, and the United States furnishes the most conclusive evidence of the high degree of approbation with which the laboring classes have hailed this new accession to their sources of pleasure and of usefulness. They have also met a favorable reception in various parts of Germany and besides the "Gewerbverein" or *Association for encouraging industry at Berlin*, we find similar institutions at Achen, Enfurt, Göerlitz, Muhlhause, Suhl, Breslaw, Sagon, Greifswalde and Dantzic.

It has been the fortune of these establishments to encounter some indirect opposition, but really to suffer from it no material injury. Their fate has been almost the reverse of that which has often awaited the plan of universal education by common schools; — for while, of the latter,

many have spoken as if they believed the great truth that our peace, honor, happiness, and national existence, depended on the universal prevalence of intelligence and good morals, they have acted as if they supposed such a notion to be utterly false; — whereas, in regard to the practical sciences and the useful arts, though persons sometimes indulge a peccant humor, and make up a pretty declamation against what they call *studying facts*, *pursuing utility*, the *rage for improvement*, and the like edifying topics of reproach, yet they have in general the good sense not to adopt in practice the spirit of their own harangues. Oh no, — they prefer comfort to discomfort.

I have referred to the fact, that by far the greater number of schools of art have been mere voluntary associations, deriving no aid even in their establishment, from the public resources, to which notwithstanding they so largely contribute. It seems probable that a more efficient and decided tone will hereafter be given to their movements, and that some plan of public endowment and support, similar to that which was so ably sketched a few years since by a committee of the legislature of Massachusetts, will ere long be demanded by the public voice. A central school for each state, would thus become a point of united interest for the public at large, and for the intelligent artizan of every name. It is inconceivable that any doubt should have been entertained as to the salutary effect of such an institution, on the character and operations of other seminaries of learning. In an establishment of this nature, with which it has been my fortune to be for some years connected, no class of the members are more constant in their attendance or more efficient in their services, than teachers and professors of every rank. Uniting frequently with great numbers of practical men in the pursuit of a common object, they derive from the intercourse, light and information which neither books, nor solitary study nor even the refinements of a more exclusive society would afford.

The several objects of well-constituted schools of art are, instruction by lectures or in such other modes as the nature of the case demands, encouragement to artizans by rewards adjudged to meritorious productions or inventions, diffusion of information by means of the press, and finally,

the prosecution of researches in natural history and of experimental inquiries in chemistry, philosophy and kindred subjects. On the first and the last of these a few remarks may not be improper.

The purpose of the instruction in a practical school, it should be remembered, is not to teach trades, but only the principles applicable to them. It should enlarge the sphere of the student's observation, by placing around him, in well stored collections, cabinets and workshops, the objects with which he ought to become familiar, and with these he should acquire by study and manipulation, a perfect acquaintance. The manual labor performed might all have a reference to the wants of the school, hence a partial acquaintance at least with the trade of the joiner, the turner, the founder and the mechanist, would of course be acquired, and these in addition to the use of the blow-pipe, the enameller's lamp and similar implements, would soon render an institution independent to a great degree on external aid for the supply of models for illustration, and of instruments for research. If placed in a situation where the arts of gardening and of agriculture can be introduced, the pursuit of these objects for both instruction and profit would naturally constitute a part of the plan. But what appears to merit more attention than has hitherto been given to it, in the institutions of our country, is the pursuit of experimental inquiries, respecting those scientific subjects with which the useful arts are mostly conversant.

Among the physical sciences, some are now so far reduced to mathematical laws as to constitute almost perfect departments of positive philosophy. But, in order to become practically useful, the mathematical principles which they embrace, must be taken with certain modifications, with which, from the nature of things, they are in practice always combined. These modifying causes are the objects of separate and independent inquiry, and constitute departments of special science, peculiarly interesting in practice, and only to be accurately ascertained by experimental researches. Abstract science then lends her aid to combine the results, with her general deductions, and to reduce the whole to a form in which they may be used by practical men.

Some few of these once void spaces in practical know-

ledge have already been filled up; as examples of which we might refer to the researches in regard to elastic vapors, — to the resistance of friction, — to the rate of cooling and other phenomena of heat, — to the best forms of bodies, designed to move through liquids, — to the strength of solid and of fibrous materials respectively, and the extent to which strains and pressures may be carried without producing permanent changes of form. These are a very few of the cases in which it has been attempted to determine by laborious experiment, the special laws of practical science.

But the points of absolute certainty, hitherto obtained, are, it must be confessed, few and far between. There is a harvest, for untold generations of inquirers yet to reap. They have no need to wander abroad into the thorny paths of doubtful disputation. Let them bring sincere and unbiassed minds, to the shrine of that truth which has been written by the hand of Omnipotence, on every page of the vast volume of nature, and they cannot fail to understand her language, — a language which though to the incurious it may seem an insignificant hieroglyphic, will one day stand revealed to some future interpreter, who entering Champollion-like into the great temple, shall bid defiance to obscurity, — lift the veil of time, and read into intelligible "phonetus" these mysterious symbols.

The vigorous prosecution of experimental science cannot with justice be referred to a period more remote than the age of Torricelli and Pascal, about two centuries ago. Indeed it has been asserted that the crucial experiment of the latter, by which he tested, beyond all controversy the truth of Torricelli's theory of the barometer — gave the first great impulse to the experimental method of inquiry, since which time the confidence of mankind in this method has been constantly growing stronger and stronger by every fresh evidence of its importance. To be impressed with the magnitude of its power we need but to mention a few facts. It had been observed at a very remote period that amber when rubbed was capable of attracting light substances, — but no developement was given because none could be given, to this most interesting observation, until the experimental method of inquiry pointed the way to those brilliant discoveries and useful applications which have been constantly increasing in number and importance

within the last seventyfive years. Again, it was observed before the days of Aristotle, that a certain ferruginous, mineral, then called *magnus* was capable of attaching to itself, as by some invisible power, small pieces of iron or steel. The philosophical toy of that day, has become, through the aid of experimental science, the guide and safeguard of the commercial enterprise and the naval power of every nation on the globe.

And again, while the principle of magnetism was thus, for a long period, made subservient to the interests of man, its nature and its relations to the other subtle agents of the universe have remained almost unknown until the same method of pursuing philosophy, taking a useful hint from significant indications, presented by electricity when acting on the compass needle, has since 1820, opened one of the most enchanting fields of both abstract and experimental research. So that instead of regarding the globe which we inhabit as one gigantic loadstone, it is beginning to be doubted whether its ferruginous ingredients, have really anything of importance to do with its directive power, except it be to disturb occasionally the general action of that force. This exemplifies the value of the same method in the formation or the correction of theoretical views. But what qualifications ought they to possess who are, by this method to advance the limits of science?

The prosecution of experiments with a view to practical and useful results, requires a combination of talents and acquisitions not frequently united in the same individual. The possession of a mind disciplined and accustomed to dwell intently on the object of its search; a habit of observing with minuteness the incidental, no less than the general phenomena of things; a patience and calmness in watching the progress of one's own labors; a familiarity with the mathematical and other scientific methods of applying the results of experiment, which may lead to the formation of general laws; — all these are indispensable in one who would extend the boundaries of science. Add to this, a mind fair and free from the trammels of hypothetical despotism, — ready to follow *truth* wherever she may lead, and willing to be instructed by *facts*, however contrary to the dogmas and theories of closet philosophy. Nor are the qualifications of *mind* alone to be studied in the formation

of a good experimenter. There must be some readiness in devising, combining, and adjusting apparatus; some ingenuity in constructing, at least in model, the implements of research which he would employ. There must be a familiarity with principles that shall enable the inquirer to judge of the proper adaptation of means to ends, so as to avoid the mortification of failures and the loss of time and resources.

In every department of philosophical investigation, the characteristics just enumerated are indispensable, but they become doubly important, when the purpose of the inquiry is not so much to trace out new paths of philosophy, as to ascertain the exact measure and bearing of those which have already been roughly surveyed. Just in proportion as science becomes *exact* and *practical*, does the demand for exact and practical talents in its investigations become the more urgent. How absurd then, is it, to imagine that a corps of experimenters to prosecute difficult, and delicate inquiries, can be called forth from the promiscuous ranks of mankind! and how evident is the conclusion, that those who would make human knowledge either more profound or more exact, must be trained by study and practice to the duties which they would undertake. The necessity for schools of experimental philosophy, where such practice may be attained, is evident upon a moment's consideration.

Now it is exactly this power of *co-ordinating* knowledge, of showing within what limits practice may safely rely on the deductions of theory, to what extent modifying causes must be taken into the account, and how far the implements and materials which man can command, are adequate to carry out and realize the results of his speculative investigations. It is this power which alone is capable of making available the truths of theoretical science, and this is the kind of power which a school of arts is fitted to develope. It is in institutions of this nature, that have been formed the most distinguished experimenters of Europe; and in such establishments as the Polytechnic school, and the School of Mines at Paris, the Royal Institution in London, and the Andersonian at Glasgow, the prosecution of these inquiries has conferred not less honor on theoretical science, than benefit on the useful arts.

The purpose of schools of the arts is not, however, merely

to give so much mechanical information as will qualify men for manual toil. They have the farther and more important object of enlarging the sphere of observation and reflection, of adorning and dignifying the character of the artizan. By learning to bring the principles of nature and of art to the test of experiment, the diligent cultivator of practical science becomes habituated to regard with most favor those precepts of moral conduct which will best bear the same test; and to look with distrust on those which shrink from such a trial. If he have diligently sought truth at original sources, at the very fountain-head, among the works of the Creator, his mind is in no fit condition to relish the mazy and misty wanderings of doubtful speculation.

Another point of view in which we may contemplate schools of art, regards them as conducive to the well-being of society, by stimulating the mind to the pursuit of knowledge for *recreation* as well as for *interest*, and thus taking the place of other resorts and other stimulants, which, unfortunately, too often usurp possession of the bodies and souls of our fellow men. Besides furnishing the community with the best artizans in every department, and good citizens fitted to serve their country in the most acceptable manner, besides making men practical in their habits, rational in their tastes, less prone than formerly to crowd certain professions where success is at best doubtful, and more inclined to seek the substantial, than the fanciful distinctions and rewards of merit, they tend to the developement of the national resources, and to the cultivation of a national self-respect. Besides proving the nurseries of powerful intellect, and aiding in the co-ordination of observed facts, they become the posts where instruction may recruit her ranks, and where the independence of a nation may find its ablest and most effective supporters.

REPORT

OF THE

COMMITTEE OF THE FRANKLIN INSTITUTE

OF THE

STATE OF PENNSYLVANIA, FOR THE PROMOTION OF THE MECHANIC ARTS,

ON THE

EXPLOSIONS OF STEAM BOILERS,

OF

EXPERIMENTS

MADE AT THE REQUEST OF THE TREASURY DEPARTMENT OF THE UNITED STATES.

PART II.

CONTAINING

THE REPORT

OF THE

SUB-COMMITTEE,

TO WHOM

WAS REFERRED THE EXAMINATION

OF THE

STRENGTH OF MATERIALS

EMPLOYED

IN THE CONSTRUCTION OF STEAM BOILERS.

PHILADELPHIA:
PRINTED BY MERRIHEW & GUNN,
No. 7, CARTER'S ALLEY.

1837.

Philadelphia, December 30th, 1836.

At a meeting of the committee of the Franklin Institute, of the State of Pennsylvania, for the promotion of the Mechanic Arts, on the Explosions of Steam-boilers, held this day at the Hall of the Institute, Prof. Walter R. Johnson, chairman of the sub-committee on the Strength of Materials, presented a report of the Experiments on the subjects assigned to that sub-committee, which was on motion read, accepted, and ordered to be printed.

S. V. MERRICK, *Chairman.*

Philadelphia, July, 1837.

Presented to the Board of Managers of the Franklin Institute of the State of Pennsylvania, for the promotion of the Mechanic Arts, and approved.

JOHN STRUTHERS, *Chairman.*

Attest, William Hamilton, *Actuary.*

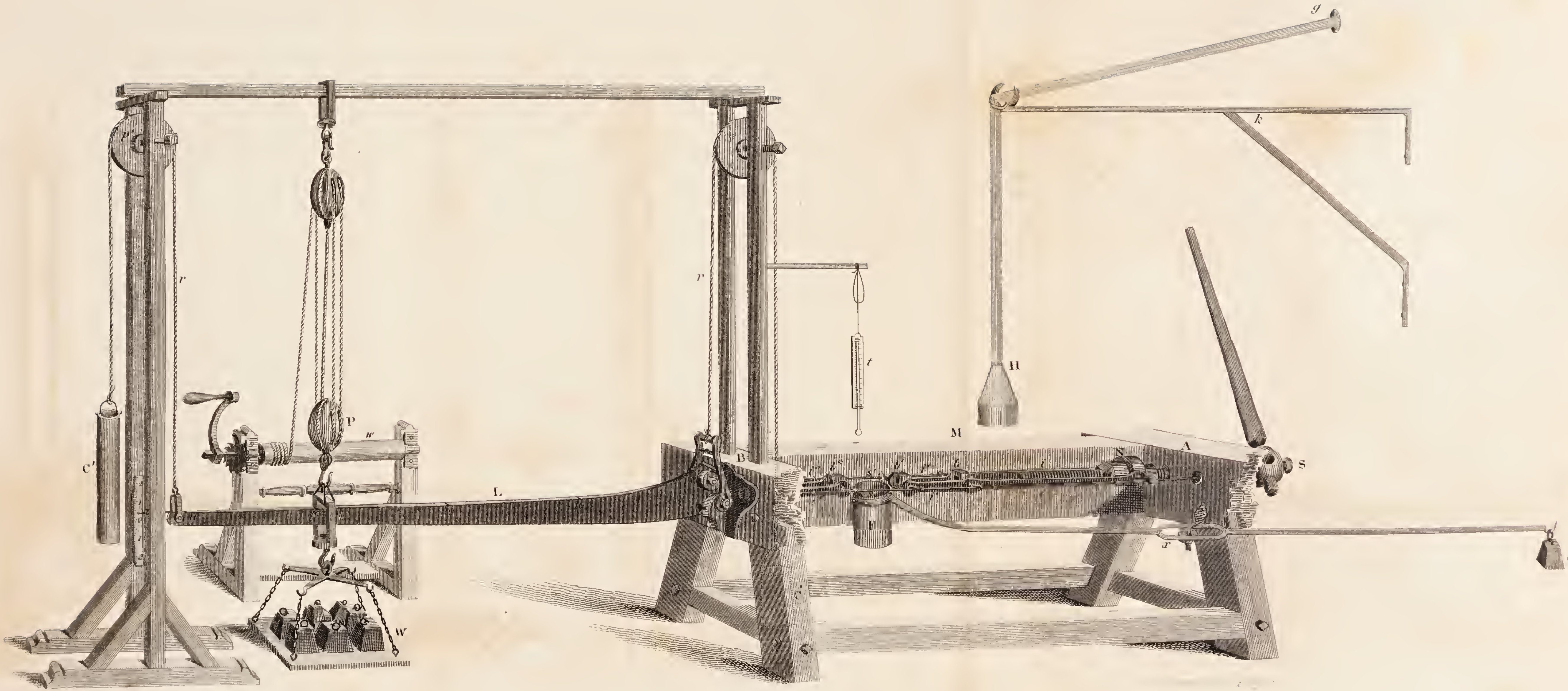
CONTENTS.

ERRATA.

Page 16, line 4 from the top, for "*w,w′*," read W,W′.
—— 37, last line, for "*containg*," read *containing*.
—— 62, column 6 of the table, transpose the Nos. 11 and 12.
—— 86, 4th column, opposite to the 14th *mark*, for .155700, read .154700.
—— 140, last line, for .097542, read .007542.
—— 150, in account of bar 217, insert *running out*, before the word puddling.
—— 206, line first, for *ar*, read *bar*.
—— 211, in the upper line, second column in the table, for °577, read 577°.
—— 214, line 33 from the bottom, for 27604, read 27605.
—— 218, line 3d from the bottom, for 6, read 0.
—— 238, on the figure at the bottom, belonging to the note at the right hand, upper corner of the parallelogram, insert *y*.
—— 239, 2d line from the top, for "*commence Fig.* 1. *from*" read *commence* (*Fig.* 1.) *from*.
—— 242, 2d line from the bottom, for "254 D," read 224 D.

On plate 2d for Table LXXIII. read Table LXXII., and on figure *n′* of the same plate, for 62295, read 62472.

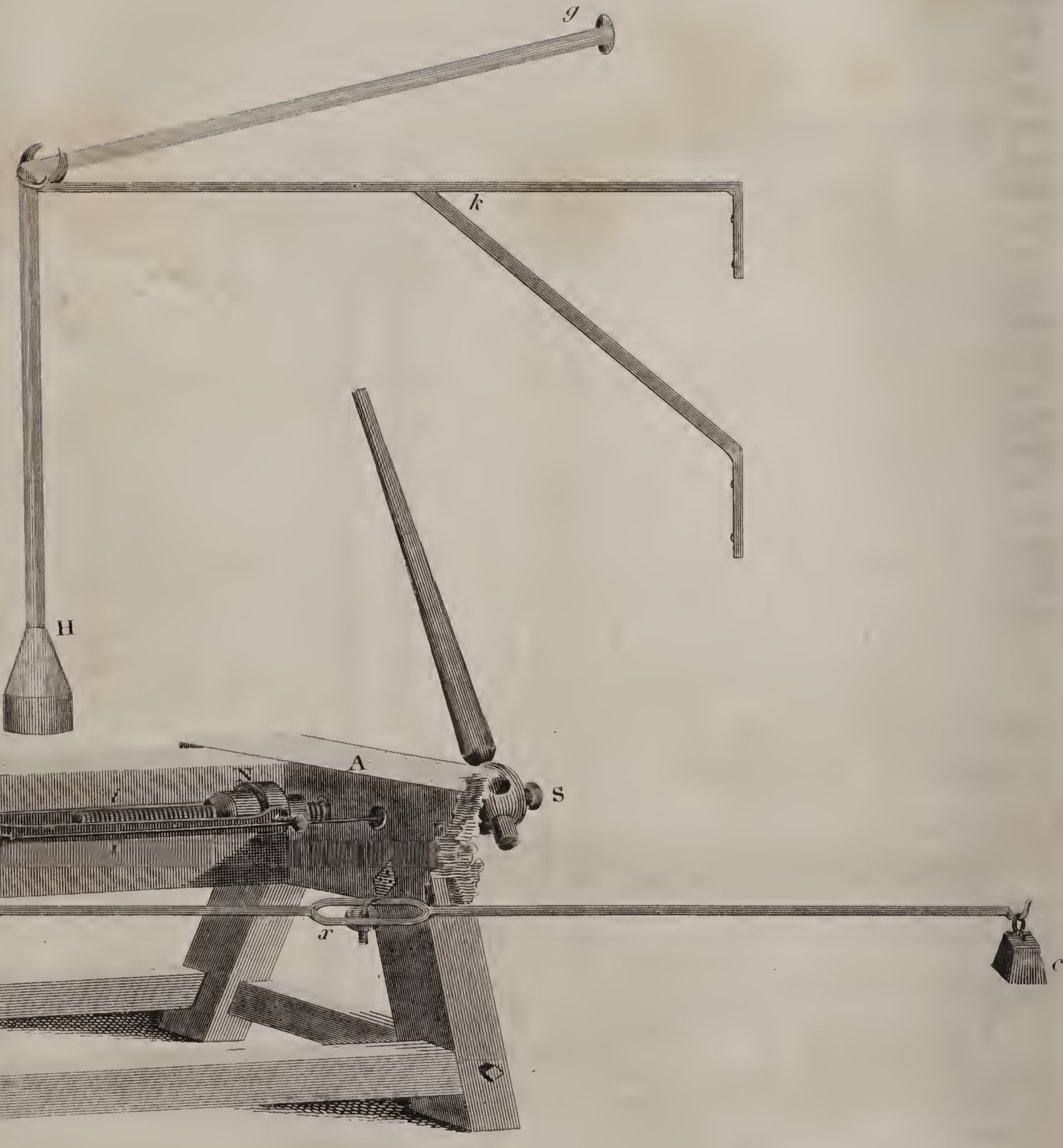
On plate 4, for "*w,w′*," near the right and left sides of the figure respectively, read W and W′.



Drawn by W. Mason

MACHINE FOR PROVING TENACITY.

Plate I.



Engraved by J.Yeager.

REPORT

Of the Committee of the Franklin Institute of the State of Pennsylvania on the Explosions of Steam Boilers, of Experiments made at the request of the Treasury Department of the United States.

PART II.

Containing the report of the sub-committee to whom was referred the examination of the strength of the materials employed in the construction of Steam Boilers.

To the Committee of the Franklin Institute of the State of Pennsylvania, on the Explosions of Steam Boilers:

GENTLEMEN—The sub-committee, to whom was referred the examination of the STRENGTH OF MATERIALS employed in the construction of Steam Boilers, beg leave to submit the following REPORT:

WHILE it is important to know the causes which may produce a dangerous developement of elastic forces in the interior of steam boilers, it is obviously not less so, to understand aright the efficacy of those means on which we rely for confining or controlling their energies. Hence, in investigating the causes of explosions, it is both natural and expedient, to examine separately those facts and principles which concern the *divellent* and the *quiescent* forces respectively. The number and variety of circumstances, which affect the character and durability of materials of which steam boilers are formed, are probably not less than of those which tend to modify the action of the fluids which they contain. In this view of the importance to be attached to the subject of the strength of materials, it may be considered remarkable, that while numerous investigations have been made as to the causes of danger, so little should have been attempted in regard to the most direct and obvious means of security. Before the series of experiments here detailed had been commenced, the necessity for such an investigation had been repeatedly pointed out, in public and private lectures, on the steam engine; the reasons assigned for instituting the inquiry, being the very general and unsatisfactory nature of those results, which are given in practical treatises, respecting the strength of metals, as dependant on the mode of manufacture, and on the different temperatures and other circumstances to which they are exposed. We had, it is true,

a considerable number of results, obtained at different periods, by experiments on the direct cohesion of wrought iron.*

They were, however, in general, undertaken for purposes very different from those which prompted the present investigation.

Few of the experimenters had in view the influence of temperatures on tenacity; and even those data which they furnish for calculating the proper thickness of metal to be employed at ordinary temperatures, in constructing steam boilers are liable to much uncertainty, owing to the diversity in the results themselves. Laborious and protracted as has been this investigation, still the practical importance of the subject has appeared to warrant a careful survey, and a diligent comparison of the various facts which might influence the practice of those who desire to attain a secure action in the steam boiler.

Without entering therefore into all the delicate questions, which, had a mere scientific view been indulged, we might have been prompted to examine, it has been the aim of the committee to obtain and present such classes of facts as both scientific and practical men may make subservient to their respective purposes.

The questions, which in the course of this inquiry, it has been found necessary to investigate, may be classed under three general divisions.

1. Principal,
2. Incidental,
3. Subsidiary.

I. *Principal.* 1. What is the absolute tenacity per square-inch bar of rolled boiler iron, at ordinary temperatures, and to what irregularities is it liable?

2. The same for rolled copper?

3. What is the effect of increased temperature on the tenacity of iron and copper?

4. What is the tenacity of wrought iron, manufactured by other means than rolling into plates;—as by rolling it into bars or rods, by hammering and wire-drawing?

5. What are the relative advantages of iron made by refining from different sorts of pig metal and their mixtures?

6. What is the comparative value of sheet iron manufactured by the processes of puddling, blooming and piling respectively, and in the last case, what influence have repetitions of the process?

* The following brief table contains some of the general results, obtained by different authors, as the strength of wrought iron.

Name of the Experimenter.	*Strength in lbs. per sq. inch.*	*Name of the Experimenter.*	*Strength in lbs. per sq. inch.*
Muschenbroek,	73.100	Telford—Swedish iron,	64.960
Perronet—on square bars,	61.083	Brown—Welsh iron,	57.075
Perronet—on round bars,	60.086	Brown—Swedish,	49.796
Buffon,	84.730	Brown—Russian iron,	59.472
Poleni,	63.390	Martin—(Fr.) St. Chambaud iron,	49.000
Rennie—on "English iron,"	55.843	Martin—Fourchambauldt iron,	47.964
Brunel—"Best English,"	68.544	Martin—Superior English,	52.823
Brunel—"Best-best English,"	72.352	Martin—English best cable,	49.251
Telford—Welsh iron,	65.520		
Telford—Staffordshire iron,	60.928	Rennie—Copper,	33.792

7. What is the effect of piling into the same slab, iron of different degrees of fineness?

8. What is the comparative tenacity of rolled iron, in the longitudinal, diagonal and transverse directions of the rolling respectively?

9. What influence may be produced, by long and repeated use, towards modifying the character of boiler iron?

II. *Incidental.* 1. What is the specific gravity of the specimens submitted to examination?

2. What elasticity is found in the metals under different circumstances of the trial?

3. What relation exists between the force which will produce a permanent elongation in a bar, and that which will entirely overcome its tenacity?

4. What amount of elongation may the several kinds of metal undergo before fracture?

5. Does the amount of *constriction* or diminution of area, at the section of fracture, bear any relation to the absolute strength of the metals, to the direction in which the strips are cut from the plate, to the breadth and thickness of the strips themselves, or to the temperature under which the trial is made?

6. What is the effect of the rivets on the total strength of a boiler?

III. *Subsidiary.* 1. What is the friction of the apparatus employed to determine tenacities?

2. What is the amount of its elasticity?

3. What is the latent heat of the vapour of water?

4. What is the specific heat of iron, copper and glass, respectively?

5. What is the rate of heating of a given mass of liquid, when subjected to the direct action of a solid of higher temperature?

6. At what rate will the same mass of liquid change its temperature by the action of air alone?

From the foregoing statement, it will be seen that more than twenty distinct topics have demanded the attention of the committee. They have felt strongly inclined to embrace some other points of great practical and scientific importance, but the time already unavoidably consumed, and the very limited means which the other branches of inquiry and experiment on explosion left to be appropriated to the purposes of this sub-committee, compelled the relinquishment, for the present, of those objects which do not immediately concern the construction and use of steam boilers.

The discussion of the questions above enumerated, will necessarily follow an order somewhat different from that in which they are here stated. A view of the apparatus, employed by the committee, claims the first notice. The origin and preparation of the materials to be tested, will also precede the detail of experiments.

Machine for proving the strength of materials.

The apparatus used, by the committee, for the direct determination of the principal questions regarding the strength of the specimens submitted to examination, is represented in plate I. M is a strong frame of oak timber, the two longer sides five feet in length, fourteen inches deep, and six inches thick.

The two shorter, or end pieces, which project beyond the *sides* to the distance of three inches, are each two feet eight inches long, seven and a half inches thick, and fourteen inches deep.

Between the two side pieces, (one of which is in the figure removed, to exhibit the interior or working parts,) is a space fourteen and a half inches

wide, affording room for a screw, cross-head, guide-rods, connecting blocks and wedges, to hold the specimens under trial; and also for the heating apparatus in experiments at high temperatures.

These four massive blocks or beams of timber, are held together by strong screw bolts, passing through mortises in the end pieces, along tenons into screw nuts imbedded in the timber of the longitudinal beams.

The frame is supported, as represented in the figure, by four firm trussel legs, six inches square, tied together near the bottom, and fastened as well to the ties as to the frame above, by mortising and bolting. The top of the frame is three feet eight inches above the floor on which the machine rests.

Through one end A, of the frame M, about six inches below the top, and centrally between the two side beams of the frame, passes the screw S, $2\frac{3}{4}$ inches in diameter, and three feet long, cut into threads $\frac{6}{10}$ of an inch apart. Near the head of the screw, is a neck turned rather deeper than the threads, to allow a clamp collar to embrace it; which, together with a strong cast iron plate, against which the head of the screw works, prevents any longitudinal motion of the screw itself.

N is the box or nut of this screw which by the revolution of S, either approaches to or recedes from the end A of the frame; *s*, *s*, are two guide-rods, one on each side of the screw, level with its axis and near the inner faces of the longitudinal beams of the frame, serving to support a cross head that contains in its central ring the nut N, and embraces by loops at its extremities the two guide-rods. The purpose of these loops is to prevent the nut from turning by the revolution of the screw.

The cross head thus secured is united by two strong straps or bars of iron *i*, *i*, 2 inches wide by half an inch thick, to a block of iron *b*, which is also furnished with two projecting arms that rest on the guide-rods already described. This block as well as the two others b' and b'' is 4 inches long, 4 inches deep, and $1\frac{3}{4}$ inches thick, being perforated centrally in the direction of its thickness with a hole in the form of the frustum of a square pyramid, the purpose of which is to admit of wedges placed within them to hold the bars of metal under trial. A more detailed description of these will be given hereafter.

The block b' is connected to *b* by a separate pair of straps i', i', and has arms reposing on the guide-rods, or when necessary, admitting a vertical semi-revolution, so as to be laid over backward between the straps *i*, *i*. This latter disposition of the block b' was made whenever specimens of 20 or 30 inches in length were to be tried; but when those of only a few inches in length were under trial, b' was used in the position represented in the figure.

The block b'' is connected by the strong iron straps i'', i'', which pass freely through a suitable opening in the head B of the frame, to the lever L. One of these straps is seen at *e*, the other being on the posterior side of the lever, with which they are united by means of a steel bolt turned with care and well polished. The straps are kept in place by a head, screw nut and washers, on the bolt. This lever is of the *rectangular* kind, the longer arm being horizontal, the shorter vertical, and the angular point being in the axis of a second or lower bolt which serves as a fulcrum.

At the end next the frame, the lever has a breadth or depth of seven inches and a thickness of one inch. Towards the opposite extremity or that on which the weights are placed, it diminishes to a breadth of four inches, and a thickness of $\frac{5}{8}$ of an inch. The upper edge of the beam is straight to within 24 inches of the broader end, where it curves upwards, affording a massive support for the upper bolt already described. In a ver-

tical direction beneath that bolt, and in the prolongation of the upper straight edge of the lever, is the position, as already indicated, of the second steel bolt, serving for a gudgeon, on which the lever turns. The distance between the axes of the two bolts is 2.914 inches, which is therefore the length of the shorter arm of the lever. The bolts are very nearly of the same diameter, being each about 1.086 inches. The lower bolt rests against a plate of cast iron, having suitable projecting cheeks, with bearings adapted for its reception.

A strap from the top of each cheek comes down over the bolt, and is fastened with a thumb screw, to prevent the lever being thrown out of place by the recoil of the machine. The two guide-rods *s*, *s*, pass through this cast iron plate, as well as through that which serves as a collar to the screw head, S, on the opposite end of the frame. The lever is formed of the best wrought iron, and weighs $164\frac{3}{16}$ pounds, the matter being so distributed that if not neutralized by counter weights, its effect in straining any bar attached horizontally to the upper bolt would have been equal to $2495\frac{1}{4}$ lbs. To obviate this, and to prevent the weight of the lever from adding anything to the friction, it is accurately counterpoised by means of weights C and C,′ corresponding to the parts of its mass which they are respectively required to sustain. Thus the weight of C, the larger counterpoise, is 103 pounds 12 ounces, that of C′ 60 pounds 7 ounces. The former is, however, increased to counterpoise likewise, one-half the weight of the two straps i'', i'', the other half resting, as will be seen, on the horizontal guide-rods *s*, ′*s*.

The axes of the pullies p, p', over which the cords r, r' pass, are furnished with cavities to receive steel pivot-points, in order to reduce, as far as practicable, the friction of these parts. The diameter of these pullies is 12 inches.

The iron stirrup, to which the cord r is attached, is applied to the lower bolt or fulcrum of the lever, the projecting ends of which roll on straight, horizontal edges, forming the bottom of two loops with which the stirrup is furnished.

By means of the suspending apparatus above described, the lever is enabled to obey any force acting vertically on its longer arm, with the advantage of ample strength and stiffness, combined with the condition of a theoretical lever, in respect to the *gravity of parts.*

There are two modes of operating by which a bar of metal, placed in the machine between b' and b'' might be broken, so as to ascertain the tenacity.

The first is to apply the force of the screw S to strain the bar in raising a weight W suspended at any convenient point on the arm h of the lever; the second is to employ the screw only to regulate the height of that arm, and to restore it when relieved of the weights, to the horizontal position, whenever the extension of the bar had allowed it to fall below that position.

The latter method was with very few exceptions, adopted by the committee,—both because it allowed of a more exact determination of the breaking weights, by a small addition at a time, and because it rendered the effect of the friction constant in its kind, being always in opposition to the gravitating force of the weight W, and *subtractive*, in the calculation.—In order to apply this mode of action without requiring correction for the stiffness of the cord r' and the friction of the pulley p', it was only necessary after adjusting the weight C′, to remove so much as would allow the arm h of the lever to descend upon the slightest jarring of the machine. The tenacity of the bar

and the friction at the fulcrum, were then the only resistances to the motion of the weight W.

The purpose of the tackle of pullies P, is to elevate the scale pan and weight after they have descended to the floor, in order, by turning the screw S, to counteract the elongation of the bar under trial, and again to commence operations with the descending motion of the arm *h*. The power of the operator is applied to the tackle by means of the windlass *w*, furnished with its crank, ratchet wheel and click. The upper edge of the lever was graduated into parts distant from each other just ten times the length of the shorter arm.

By the aid of these several appendages, the machine allows the most gradual additions to be made to the divellent force applied to the specimens, breaking each with a descending movement, and consequently, rendering the *friction* definite in the direction of its influence, being, as before stated, always subtractive.

The very few cases in which the mode of operation rendered it *additive*, are particularly mentioned in the tables.

At the outer extremity of the lever, and in the prolongation of its upper edge, is placed a style *z*, serving as an index to the graduated arc *a*, which is divided into minutes of a degree. The point of the style is 10 feet 3 inches from the axis of motion in the lever, and the length of the entire circumference which it would describe 772.8276 inches. Hence each degree is 2.14674 inches, and each minute, as measured on the arc, is .035779 of an inch. The whole extent of the arc *a* is about 5 degrees, the zero, or point of horizontal position being placed 3 degrees from the upper extremity. The chief use of this arc was to determine approximately the *elasticity of the bars*, and of the machine itself, as preliminary to that inquiry. The weights W, in the scale-pan, (which, with its suspending chains, cross-bars, &c. weighs 56 pounds,) were, in every case, applied on the lever, at the third mark, a distance from the axis of motion 30 times as great as that between the axes of the two bolts, or $30 \times 2.914 = 87.42$ inches.

Friction of the Machine.

The amount of friction of the machine already described for testing the tenacity of metals, was an object requiring particular investigation before any thing more than a comparative value could be assigned to the results which were afforded by the experiments.

To determine this point, it was deemed advisable to ascertain under various loads what proportion the weight which was sustained by the machine, after it had been raised by the screw S till the index stood at zero on the arc *a*, bore to that which, after the lever was relieved and then loaded again with the same weight, would cause it once more to descend to zero.

Between the heads b' and b'' was placed a strong bar of iron 1 inch wide by $\frac{3}{4}$ of an inch thick. Two methods were then pursued for the purposes of mutual verification.

1. A certain weight was placed in the pan suspended at *h*, and the screw S turned until, as before mentioned, it was raised to a level so that *z* stood at zero on the graduated arc. The windlass *w* was then employed to raise the scale-pan and entirely relieve the lever. On again restoring the weights, the index remained some minutes of a degree above 0, and an additional quantity of weight was necessary, to bring it once more down to that level. As, in this case the weight added served to increase the friction, it is manifest that the comparison of it with the whole weight, itself in-

cluded, must be necessary in order to show the relation between the weight at first raised and that part of it, which represented the friction of the machine. When the weight was raised by the screw, the bar which connected the heads b' b'', must have sustained a strain composed of the weight raised *added to* the friction of the machine; whereas when the weight was let on by the windlass while the index was at some distance above 0, the bar sustained a strain represented by the weight borne, *diminished by* the friction.

II. The lever was caused to rest on a solid support near the extremity, the index being opposite to zero on the arc, and in that position the scale-pan was loaded with the weight under which it was intended to try the friction. The screw S was then carefully turned to strain the bar and bring the loaded arm of the lever barely off of the support. The weights were next raised by the windlass and the recoil of the machine raised the lever to a certain elevation, from which it was once more depressed by replacing the weights upon it, and adding such an amount as would just depress the arm to the level of its original support.

The first of the above methods gives the *double*, and the second the *single*, friction of the machine. The following table exhibits the weights in the scale-pan, the weight representing the friction when the first method was employed; the same for the second method; and the ratio of the friction to the total weight sustained by the lever. A correction is required particularly at the higher pressures, on account of the increased elasticity in the machine under the added weights, which actually brought the index down to zero sooner than it would have arrived at it, by the simple effect of a strain upon the lever regarded as inflexible.

The machine was kept constantly well oiled, still a trifling difference may possibly have existed in regard to its condition at different times; but no influence of this sort, was ever found sufficient to determine the rupture of a bar, after the weight had been taken up, the gudgeons newly oiled, and the same weight replaced, which it had borne previous to that operation.

TABLE I.

		Double Friction.			Single Friction.		
No. of the experiment.	Weight applied to the lever.	Weight required to counterpoise the double friction.	Ratio of friction to weight by the method of double friction.	No. of repetitions furnishing the mean result on double friction.	Weight required to counterpoise single friction.	Ratio of friction to weight by the method of single friction.	No. of repetitions furnishing the mean result on single friction.
1	56	6.00	.050+	3	3.00	.050+	1
2	112	10.82	.051+	7	5.79	.051+	6
3	168	17.62	.052+	4	9.06	.051+	4
4	224	24.85	.055+	10	12.75	.053—	5
5	280	28.16	.050+	6	14.71	.050—	7
6	336	35.30	.053+	5	17.25	.049—	6
7	392	38.33	.047+	4	20.42	.050—	4
8	448	42.50	.048+	4	22.64	.048+	7
9	504	45.50	.045+	1	26.80	.050+	7
		Mean	.050	Tot. 44	Mean	.050 5	Tot. 47

From the above table it appears that the second method gave results more nearly in accordance with each other than the first, but it will also be noticed that forty-four observations with the first gives a mean value sensi-

bly identical with that obtained from forty-seven experiments with the second method of trial above described. We were hence led to adopt 5 per cent. of the weight as the effect of the friction of the machine. The bolts are of well polished steel and the lower bearing of cast iron, and the upper one or the eyes of the straps i'', i'', of wrought iron.

This relation of friction to pressure between these substances as deduced from the experiments of the committee, will be found to correspond very nearly with that obtained by Mr. Wood when operating on railway carriages.*

Elasticity of the Machine.

In order to determine, in particular cases, the amount of elasticity exhibited by the bars under trial, it became necessary to ascertain the elasticity of the machine, when loaded with different weights. Several series of trials were accordingly made expressly with a view to this object.

Putting into the machine, in place of a bar to be broken, one which was intended not to yield sensibly to the strains applied, and not in any case to be permanently elongated by them, different weights were appended to the lever, and allowed to remain until the latter had become stationary. They were then carefully raised by the windlass, and the lever allowed to rise by the recoil until it became entirely free from strain. The number of degrees and minutes on the arc a, traversed by the index, was then noted; the weight replaced, and the trial repeated until it was ascertained that no error of observation had occurred.

Three series of operations were performed each beginning with the lever 3°. 30′ above zero, when entirely unloaded, but fully in contact with its bearings. Weights were then added by 56 pounds at a time, and the depression below 3°.30′, produced by each addition, was noted. This was continued until weights had been added sufficient to bring the index to 0, which was effected with 11 weights of 56 pounds each.

If the *lever* had been entirely inflexible, the natural sine of the angle of elevation after being relieved might have been considered the measure of the compression of parts sustained by the frame, links, &c. under each weight; for as the shorter arm of the lever is only 2.914 inches in length, while the bar and connecting straps are more than 5 feet, the direction of the horizontal bar may be considered sensibly constant.

The following table contains the results of the experiments just described, together with those of another set in which the operations were in every respect similar, except that the weights were applied by 37½ pounds at each time instead of 56 pounds. The natural sines are added, by comparing which with the respective *compressing forces*, it will be found that the law which governs the *elasticity* of the machine is, that *the latter is proportionate to the fifth root of the cube of the compressing force.*

* See Wood on Railways, Smith's edition, Philadelphia 1832, p. 202. The mean of nine out of twelve experiments there detailed is exactly 5 per cent. for the friction between steel and cast iron.

TABLE II.

No. of the trial.	Weight in pounds producing compression.	Recoil of the lever in minutes of a degree.	Natural sine of the angle of elevation of the lever after the recoil.	REMARKS.
1	37.5	40.′	.0116353	Comparing the first with the last experiment by the formula $\left(\frac{616}{37.5}\right)^x = \frac{\text{nat. sin. } 211.5'}{\text{nat. sin. } 40'}$
2	56.	47.2	.0136713	we get x=0.594.
3	75.	58.	.0168707	The 3d and 16th, by a similar comparison, give x= 0.608.
4	112.	74.7	.0218149	The 4th and the 19th give x= 0.606.
5	150.	86.	.0250138	
6	168.	95.	.0276309	The 6th and 8th give x= 0.600.
7	187.5	100.	.0290847	The 7th and 17th give x= 0.627.
8	224.	112.7	.0328644	The 8th and 10th give x= 0.595.
9	262.5	120.	.0348995	
10	280.	128.7	.0375158	The 10th and 12th give x= 0.560.
11	300.	134.	.0389692	The 11th and 18th give x= 0.641.
12	336.	143.4	.0415850	
13	375.	154.5	.0447818	The 13th and 15th give x= 0.583.
14	392.	157.4	.0456536	
15	412.5	166.3	.0482687	
16	448.	171.9	.0500119	
17	504.	186.	.0540788	The 2d and 17th give x=0.625 Mean 0.603
18	560.	199.7	.0581448	Hence the mean of the above 10 comparisons gives x=.603, which, by rejecting the
19	616.	211.5	.0613389	last figure, furnishes the law above stated.

Another set of trials was made, loading the lever with weights by 7 pounds at a time from 0 to 609 pounds; and from the results of this and the preceding series a table was constructed, furnishing the column of elasticities of the machine for every observed depression under given weights when testing the elasticity of bars of iron. By deducting the elasticity due to the machine alone from that obtained by observation, we get the measure, in minutes of a degree, of the elasticity of the bar.

In the table of elasticities actually observed will be found various numbers between 5′ and 73′. To facilitate the comparison of each observed elasticity with the length of the bar on which the trial was made, the following table is annexed in which the natural sine belonging to each number of minutes has been multiplied by 2.914, the length in inches of the shorter arm of the lever.

TABLE III.

Observed elasticity in parts of the arc.	Corresponding extension and recoil of the bar in inches.	Observed elasticity.	Extension and recoil in inches.	Observed elasticity.	Extension and recoil in inches.	Observed elasticity.	Extension and recoil in inches.	Observed elasticity.	Extension and recoil in inches.
5′	.0042323	19′	.0160829	33′	.027965	47′	.039835	61′	.051695
6	.0050788	20	.0169295	34	.028821	48	.040680	62	.052539
7	.0059253	21	.0177760	35	.029665	49	.041529	63	.053385
8	.0067718	22	.0186525	36	.030508	50	.042370	64	.054230
9	.0076183	23	.0194690	37	.031360	51	.043223	65	.055076
10	.0084648	24	.0203455	38	.032200	52	.044060	66	.055920
11	.0093114	25	.0211618	39	.033050	53	.044903	67	.056792
12	.0101579	26	.0220083	40	.033839	54	.045750	68	.057639
13	.0110041	27	.0228548	41	.034769	55	.046596	69	.058484
14	.0118506	28	.0237013	42	.035580	56	.047439	70	.059330
15	.0126972	29	.0245478	43	.036425	57	.048288	71	.060173
16	.0135437	30	.0253941	44	.037270	58	.049158	72	.061019
17	.0143902	31	.0262406	45	.038115	59	.050009	73	.061865
18	.0152367	32	.0270871	46	.038989	60	.050848	74	.062710

Instead of the numbers in the table, a tolerably near approximation to the true temporary elongation corresponding to each observed elasticity of the bar in minutes might have been obtained, by multiplying the number of minutes by .000847 inch, the length of one minute on the arc of a circle, the radius of which is 2.914 inches. This would give a result sensibly correct, especially for all numbers of minutes under 60.

Sources from which the materials were obtained.

The materials on which the committee have performed the experiments detailed in this report, were procured from various sources, a considerable quantity having been collected previous to their appointment by one of its members, then making arrangements for a private course of investigations on several scientific and practical points, relating to tenacity. Other specimens were voluntarily offered, or kindly supplied at the request of the committee by the different manufacturers, or other persons to whom application was made for that purpose. In several instances, more specimens of the same iron were furnished than will be found mentioned in the tables as derived from the same quarter;—the whole number obtained being about two hundred and fifty, and the number tried about one hundred and fifty. As the aim of the experiments was the establishment of such practical truths as might be found generally useful in regard to the manufacture and employment of materials for steam boilers, it was not deemed necessary to enter into a minute comparison of the merit of different manufacturers from whom the materials were received, nor to limit the inquiry to any given number of specimens or of trials on those derived from each source. The reader, will, however, be able to institute such comparisons as his curiosity may dictate,—the tables furnishing all the facts, (as well as the names of the manufacturers when known,) which have been obtained by the committee, in regard to the origin and manufacture of the different specimens.

Among the names of those from whose manufactories specimens have been received, are Messrs. Mason & Miltenberger, H. S. Spang & Son, Barnet Shorb, H. Blake & Co. and Shoenberger & Son, of Pittsburg; S. E. H. & P. Ellicott, and E. T. Ellicott & Co. of Baltimore; the Salisbury Iron Company, of Salisbury, Connecticut; Messrs. Yeatman & Woods, of Nashville, Tennessee; Mr. Massey, of Maramec, Missouri; R. Lukens, of Coatesville, Chester county, Pennsylvania; George Pennock, McWilliamstown, in the same county; Messrs. Grubbs, Lancaster county, Pa., Hardman Phillips, Esq., Clearfield county, and Messrs. Valentine & Thomas, Centre county, Pa. To Messrs. A. & G. Ralston the committee were indebted for specimens of boiler, bolt, and railroad iron, of English manufacture, which served as means of comparison between the foreign and the domestic material, and from other importers they procured those of Russian and Swedish manufacture, for the same purpose. All the samples of American iron thus far mentioned, were manufactured by the aid of charcoal. A single specimen furnished by Mr. P. Ritner, of Carthouse's Place, on the West Branch of the Susquehanna river, was made by smelting with coke.

The specimens of boiler copper, tried by the committee, were obtained from the establishment of John M'Kim, jr. & Son, of Baltimore.—To the above, and several other gentlemen who were active in procuring the materials, and otherwise forwarding the objects of this inquiry, the committee are bound to offer their grateful acknowledgments.

Preparation and gauging of the specimens.

The experiments were made on materials in several different forms, and as the results are in some measure dependent on the circumstances now referred to, it seems proper to describe those several conditions, together with the method of obtaining the areas of transverse sections at the points of fracture.

As the greater number of experiments was, of course, made on materials manufactured expressly for steam boilers, the mode of preparing these is of most importance. The strips were in general cut, by shears, from the plates, about 2 or 2½ feet long, and 1 inch wide; and with a view to determine the tenacity in different directions, they were cut either lengthwise, crosswise or diagonally of the direction in which the plate had been rolled.

The tables will be found to indicate, in all cases where rolled iron is under consideration, the direction of the slitting.

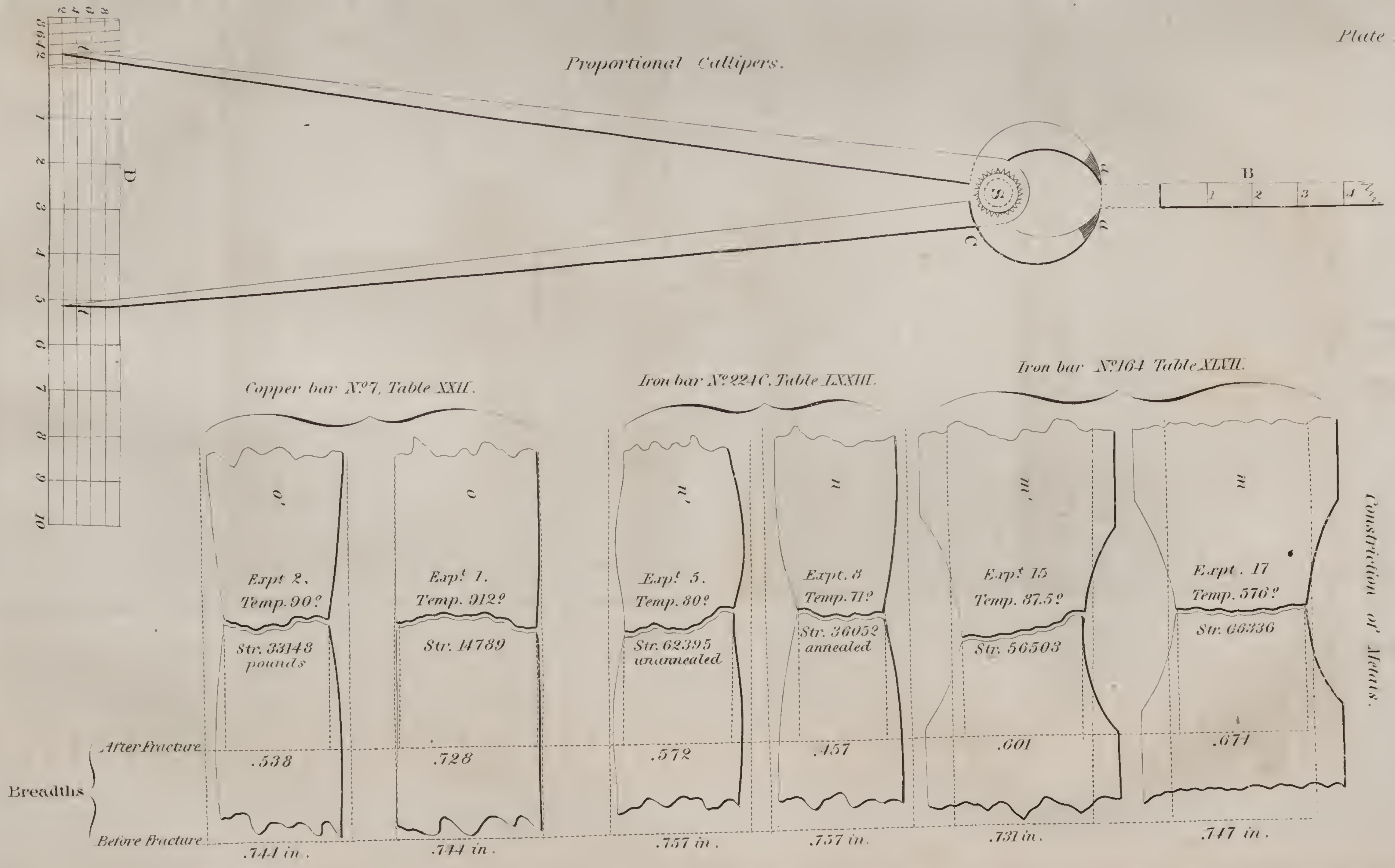
On specimens of this kind, trials were made in three ways. *First*, by finding and measuring the area of the smallest section, as the strip came from the shears, and placing it in the machine, applying force till that or some other section gave way. When not broken at the smallest section, the actual area of the point of fracture was ascertained approximately by measuring, after fracture, at a short distance on each side of the broken part, taking care to keep just outside of the constriction or part sensibly diminished by the strain. After thus determining the area previous to trial, a portion of the bar was replaced, and other fractures made, until the specimen had been used up. Fractures on bars, tried in this manner, are referred to in the tables as made at *original sections*. But as the slitting of bars in the manner described necessarily caused some diminution of strength along the edges, and as from accidental causes this diminution was often very unequal, it was apparent that the irregularity in the *strength* migh

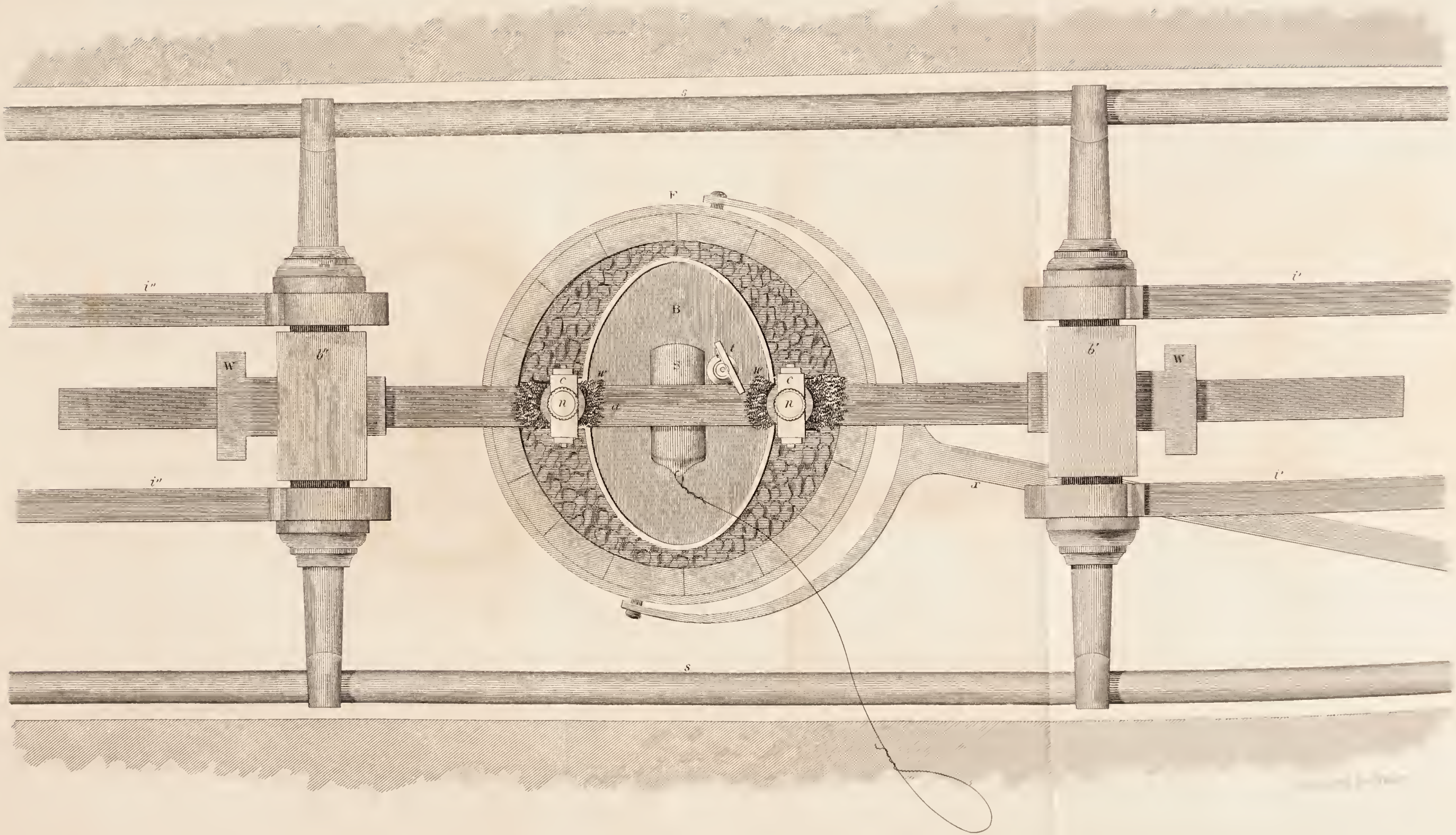
frequently be greater than that in the *breadth* of a strip. To ascertain the mean effect of the shears on bars of this breadth, the second method of trial was adopted.

This consisted in filing away a section of the metal on each side of the strip, in the form of the segment of a circle. At different points, these sections were filed to different depths, with a view of ascertaining how far beneath the surface the metal had been affected. The scale of oxide was also in some cases filed from the surface, but in most instances where the rolls had left the iron tolerably smooth, it was thought best to take the measurements of thickness, as they must be taken in practice with the surface in its natural state. In some instances, it will be found that the fractures did not occur in the filed section, even when a considerable portion of the whole material had been filed away, (see bars 206 and 207, &c., table LII.) In general, however, about $\frac{1}{8}$ of the breadth of the bar being removed by the two opposite sections, the sound part of the metal was attained, and gave results nearly proportionate to the areas of the remaining sections.

But as neither the rolling nor the hammering of iron can give a perfect uniformity of structure, and as consequently the results on very deeply filed sections would not always prove uniform in their indications of strength, it became necessary, in order at once to remove the irregularities proceeding from the slitting, and to compare the advantage of different modes of manufacture, and different kinds of metal employed, as well as to ascertain the maximum and the minimum strength of the same bar at various temperatures, to employ the third method of preparation, that of filing away the edges of the inch bars till they were reduced to $\frac{3}{4}$ of an inch in width throughout their whole length, and also removing completely the scale from both faces, and rendering the thickness as nearly as possible uniform throughout. The bars treated in this manner were next divided through their whole length into spaces of one inch each, marked across with a steel point, numbered at every inch, and subsequently gauged at every mark, both in breadth and thickness. In these measurements, as well as those applied in the two other methods of preparation, the gauging was carried to thousandths of a lineal inch in both directions, giving the areas, true to millionths of a superficial inch. Plate II represents the apparatus used for this purpose, and a portion of a bar prepared for gauging. C is a pair of proportional callipers of brass, pointed at a, a, with steel. S is a screw head projecting $\frac{1}{2}$ an inch above the face of the instrument, and is $\frac{1}{3}$ of an inch in diameter, being a trifle less in length than the thickness of the two arms of the callipers. The distance $S\,t$ is ten times that of $S\,a$, so that the space beween the points a, a, is read into tenths, hundredths and thousandths, when that between t, t, on the diagonal scale D, is found in inches, tenths and hundredths.

Specimens of hammered iron and of iron formed into bars by rolling and slitting were tried with a view to certain comparisons and in these cases all the three modes of preparation applied to specimens of boiler iron were likewise employed. In a few instances specimens were received from the manufacturers in a form which required no alteration before trial, but in the majority of cases they were to be either slit or hammered and filed to adapt them to the purpose of these experiments. In the treatment of boiler-iron, *heating* before trial, was, with few exceptions, avoided. The tables will be found to contain a few experiments on upsetting, annealing and hammer-hardening. They will also exhibit a very limited number of trials on cast iron and steel, but as these materials enter sparingly into the composition of steam boilers, and as their tenacity has been formerly much more exten-


Proportional Callipers.
B
1
2
3
4
a
a
S
C
D
t
t
8 6 4 2
1
2
3
4
5
6
7
8
9
10
Copper bar Nº7, Table XXII.
Iron bar Nº224C, Table LXXIII.
Iron bar Nº164 Table XLVII.
o'
o
n'
n
m'
m
Exptˢ 2. Temp. 90º
Exptᵗ 1. Temp. 912º
Exptᵗ 5. Temp. 80º
Expt. 8 Temp. 71º
Exptᵗ 15 Temp. 87.5º
Expt. 17 Temp. 576º
Str. 33148 pounds
Str. 14789
Str. 62395 unannealed
Str. 36052 annealed
Str. 56503
Str. 66336
Constriction of Metals.
After Fracture
Breadths
Before Fracture
.538
.728
.572
.457
.601
.671
.744 in.
.744 in.
.757 in.
.757 in.
.731 in.
.747 in.


F
B
i''
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i'
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n
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w
a
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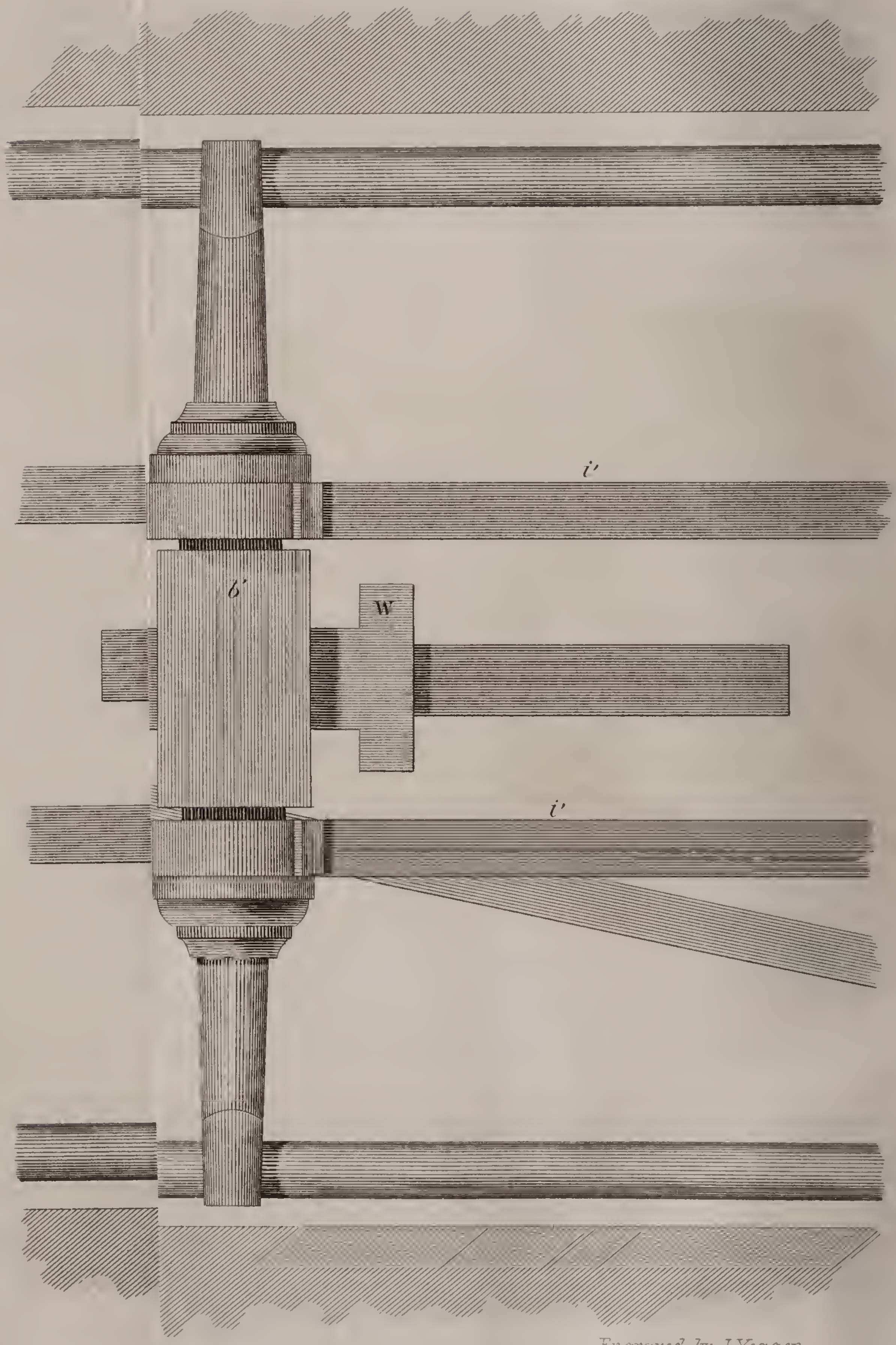
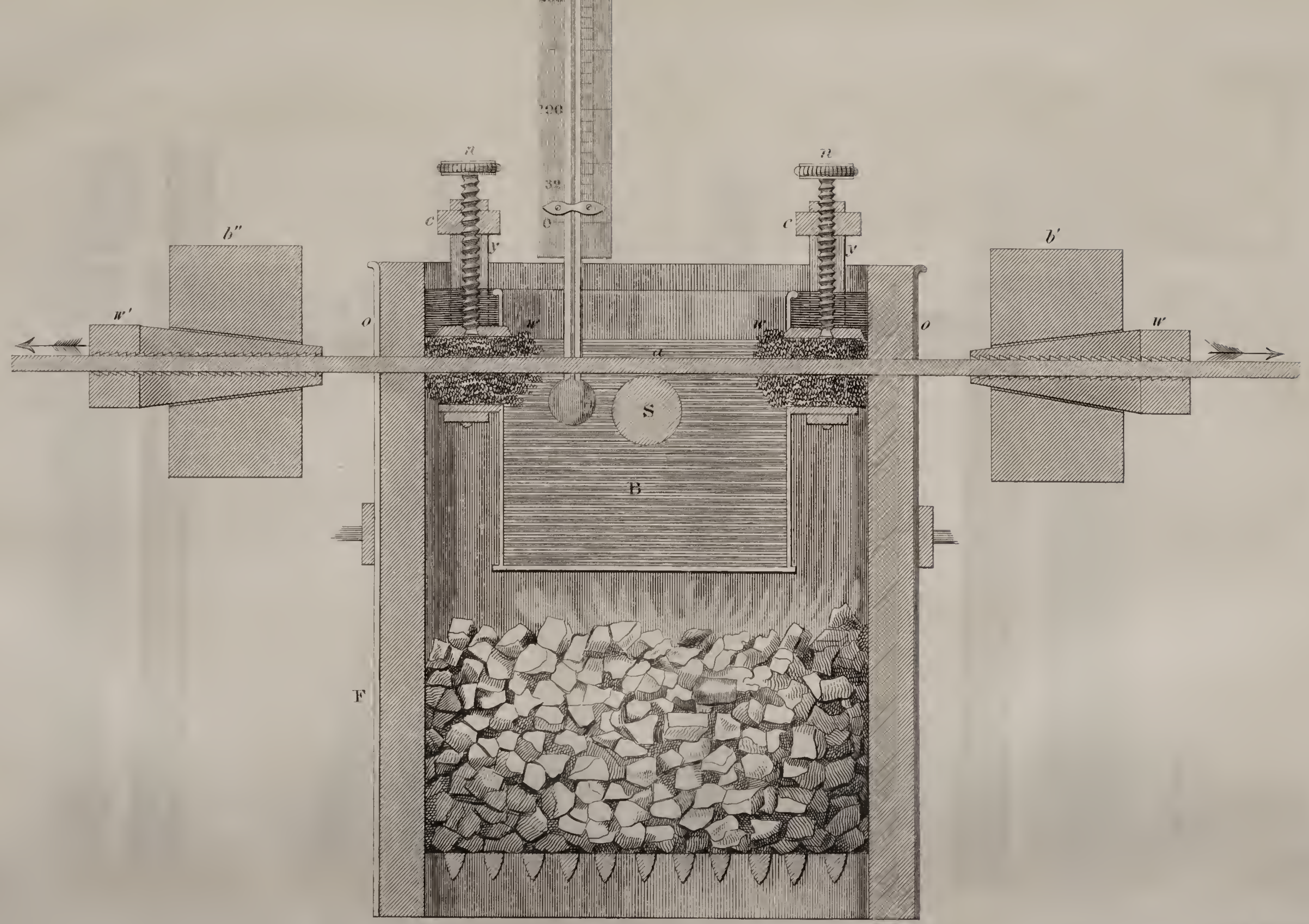
s
s

Plate III.



Engraved by J. Yeager.



Engraved by J. Yeager. Wm. Mason Del.

sively examined than that of boiler-plate, it was not considered within the purpose of the present investigation to do more than present a few verifications of the correctness of those results on which practical men commonly rely.

The bars of cast iron were tried as they came from the mould, or with very little filing to remove the irregularities of the surface. The specimens of copper were all reduced by filing to a good degree of uniformity, and gauged as already described.

At the foot of each column of original areas in each bar gauged throughout its length, will be found the mean area, and under areas of "sections of fracture" are the mean areas of the points broken.

Apparatus for High Temperatures.

The general arrangement of the parts of apparatus expressly designed for experiments, at the highest temperatures, is presented in plate I., where F is the portable furnace for charcoal, suspended by an iron ring which is fastened on near its upper edge, and attached by means of pins on the opposite sides, to the two ends of a semi-circular fork on one arm of the lever x. The weight of the furnace and its contents is counterpoised by the weight c. About the centre of the lever is a slit, 6 or 7 inches long, through which passes the end of a screw suspending-rod. The nut belonging to this screw, is furnished, on its upper surface, with an elevated ridge, serving the purpose of a knife-edge, which applies at pleasure to any one of several transverse notches on the under side of the lever along the slit This serves, for the time, to fix the lever and to prevent its sliding endwise unless when lifted from its bearing.

As this nut revolves freely on the screw, a horizontal motion about the screw as an axis is readily given to the lever, while, to raise or lower the furnace in order to regulate the temperature, the knife-edge on the nut affords ample facility. The top of the furnace rises between the two guide-rods s, s, and between the two iron blocks b' and b'' within which the bar to be tried, is confined. When not in immediate use, the furnace is swung round beneath the beam of the frame M, and placed under the cap H, the pipe of which is supported on the end of the crane R, adapted for its reception, and passing into a chimney at g. The Thermometer t, suspended from an arm projecting beyond one of the uprights which support the pulley p, is lowered, when in use, into a bath of hot liquid through which the specimen under trial passes, as described below. The details of the arrangement are seen in plate III., where a plan is given of so much of the machine as may be necessary to comprehend the manner of fixing the bars and of applying the heat. In plate IV., a vertical section through the length of the bar, is exhibited; the references in both these plates, being, so far as they apply to common objects, the same as those in plate I. Thus in plates III. and IV., i', i' and i'', i''. are the straps of iron connected with the blocks b' and b'', which by means of their projecting arms repose on the two guide-rods s, s. F is the furnace, t the thermometer seen immersed in the bath of hot liquid B, and x is the lever supporting the furnace. The bath is composed of an elliptical copper or sheet iron cup, $4\frac{1}{2}$ inches long, $3\frac{1}{2}$ wide, and 4 inches high with two lips or channels, in the direction of its shorter diameter, each one inch deep, and the same in breadth, to admit the passage of the bar through them, and to contain the packings w, w, adapted to retain the hot liquid, and cause it to cover the bar a. These channels extend each about one inch beyond the sides of the cup, affording room for the straps y, y, passing beneath them

and rising on each side, near the tops of which are placed two cross-heads, *c*, *c*, and through these pass the tightening screws *n*, *n*, employed in pressing down the packings *w*, *w*. The manner in which the bars are held by the blocks b', b'', is seen at *w*, w', where the dove-tailed form of the holes into which the wedges pass and the arrangement of teeth on the steel face of each wedge, are particularly indicated. In adjusting the bars in their place for these experiments, it became necessary to form perfectly secure joints at *w*, *w*, where they pass through the channels before mentioned. In most of the experiments below 600 degrees this was effected by means of loosely spun cotton, wrapped about the bar, for an inch at each point where the screws were to be applied. For temperatures above 600° a packing formed of fibres of iron scraped from wire in the manufacture of weavers' reeds was adopted. This being formed into mats, and rolled in a powder of oxide of tin,—constituted an impervious barrier to the melted metal, particularly after being duly settled and condensed into place, and then firmly compressed by the screws.

Below 600°, the fluid commonly employed was olive oil, and for higher temperatures a mixture of tin and lead. In some cases, however, between the melting point of *tin* and the highest temperatures applied, the latter metal only was used.

The source of heat for moderate temperatures was either a single or a double-wick spirit lamp, of Dr. Mitchell's form. When the latter proved inadequate to supply the desired temperature, the furnace of charcoal F was substituted, and, by means of notches *o*, *o*, at its upper rim, it was raised so high as completely to embrace the bath B as represented in plate IV.

Standard of High Temperatures.

The standard of temperatures below the boiling point of mercury was the mercurial thermometer. Above that point the instrument adopted by the committee, was the steam pyrometer described in the *American Journal of Science* vol. xxii. page 96, by Prof. W. R. Johnson. At S, plates III. and IV., is the standard piece of wrought iron laid horizontally beneath the bar *a*, and kept in its place by the buoyancy of the mixture of tin and lead, the superior density of the latter metal serving to float the iron, and the higher specific heat of the former, keeping the temperature of the bath more steady than it would have been if lead alone had been employed.

As several improvements have been made in this pyrometer since the date of its first publication, which are conceived to be important in point of accuracy and despatch, it is proper that we should present a view of its structure as used in these experiments, together with a concise statement of the mode in which the latter were conducted.

The instrument is founded on the supposition, that from a mass of water already in ebullition, a weight of vapour may be generated, by immersing a solid, of known weight and capacity for heat, which shall be proportioned to the temperature of such solid above the boiling point of water. In this supposition it is, of course, implied that the specific heat of the solid is constant, or that we allow for its variations ;—that during the experiment no heat is received by the water from any other source than the hot solid immersed, and also that vapour ceases to escape, as soon as the solid has been cooled, by vaporization, from the initial temperature, down to that of boiling water. It is further requisite that no heat from the immersed solid be expended in any other way, than the production of vapour by passing from a sensible to a latent state. A convenient apparatus for ascertaining

the weight of vapour thus expelled by the hot body, used as a standard piece, is another requisite.

In almost all the usual processes of weighing, the time occupied in making an adjustment of the counterpoise, is too considerable to admit the supposition that no loss of vapour from an open vessel of hot water would take place, between the time when the solid attains the boiling point, and that when the equilibrium would be reproduced. To answer the conditions above indicated, the steam pyrometer is constructed in the form represented in plate V. A is a cylindrical boiler, 12 inches high, constructed of two concentric cylinders of tinned sheet iron, between which is a stratum *n*, *n*, half an inch thick, of dry charcoal-dust, (lamp black,) to serve as a non-conductor and preserve the water within, from loss of heat by radiation during the experiment.

The bottom is formed of a single sheet of the same metal connected with the lower edge of the inner concentric cylinder, and rising in the form of a segment of a sphere to the height of $\frac{3}{4}$ of an inch, in order to present an enlarged surface to the action of the lamp L, which keeps the water in ebullition until the moment when the solid is immersed. *t* is a thermometer bent at right angles $\frac{3}{4}$ of an inch from the bulb, and passing along a tube opening into the boiler. A packing around this part of the stem prevents leakage, and the bulb being wholly immersed in the water, serves at all times to indicate its temperature, and particularly to mark the moment when that of the solid has descended so low as to cease generating steam of *atmospheric tension.*

Mode of ascertaining the weight of vapour expended.

The mode of suspending the boiler to the beam of the balance, is seen at *m* where the dotted prolongation of the beam B forms a forked curve rather greater than a semicircle, each extremity of the arc *m*, *m*, (Fig. 2.) being turned inward so as to stand at right angles to the direction of the beam; this brings the two bearing edges which support short hooks attached to loops on the opposite sides of the boiler, into the same line parallel to the main axis or knife edge *f*, at the central part of the beam. These parallels are exactly 12 inches apart. The opposite arm of the balance beam is cylindrical, and cut into a fine threaded screw to within an inch and a half of the fulcrum *f*, where the beam is divided for a certain space into two portions (*x x*, fig. 2.) between which passes the upright rod of the supporting stand. The beam used during a considerable part of the experiments contained $150\frac{1}{4}$ threads in one foot of the length of the screw, and was $\frac{1}{2}$ an inch in diameter. At the highest temperatures which the committee had occasion to measure, the number of threads passed over in one experiment, did not exceed $11\frac{1}{20}$ or so much as to measure from 1100, to 1200 degrees of temperature.

By a careful measurement of different numbers of threads, selected at various parts of the screw-arm, (which was 16 inches long) it was ascertained that, though at the two extremities, the threads differed slightly from their mean length, yet at the middle portion, where the revolving counterpoise P is represented in the figure, no appreciable difference could be detected, and as this was the part always occupied by the weight, the instrumental error from this source may be considered altogether unimportant. In fact the extremes of the variation just referred to taken most unfavourably, could not have in the highest temperatures, amounted to more than 7 degrees Fah., which at points so elevated as 13 or 1400 degrees, would not be deemed a very important inaccuracy.

But even this was avoided by occupying that part of the screw where the threads were of equal length; and by making an adjustment of the balance and weighing any given body placed on the boiler, with the counterpoise in different parts of the range selected for the experiments, it was easy to verify the accuracy of the measurements and determine precisely the error, if any had existed. But this method when tried, only served to confirm the result of the other.

The revolving counterpoise.

On the screw already described, was placed a revolving counterpoise P, which, together with its index I, placed on a neck projecting beyond the base of the cylinder, weighed 10517 grains; consequently, as each thread of the screw measured 0.07872 of an inch, the motion of the counterpoise over one thread was equivalent in effect to a weight of 100 grains applied at that end of the beam where the boiler is suspended, or $\frac{1}{100}$ part of a revolution marked a difference of one grain in the weight of water in A.*

* The method used in determining, by calculation, the true adjustment of parts and the graduation of the scale of the steam pyrometer is equally applicable, whatever may be the length of the weighing beam, or of the threads of the screw, and whatever the nature of the material employed for a standard piece, the latent heat of vapour, the kind of liquid from which it is produced, or the scale of thermometer to which we refer the indications, marked on the revolving counterpoise.

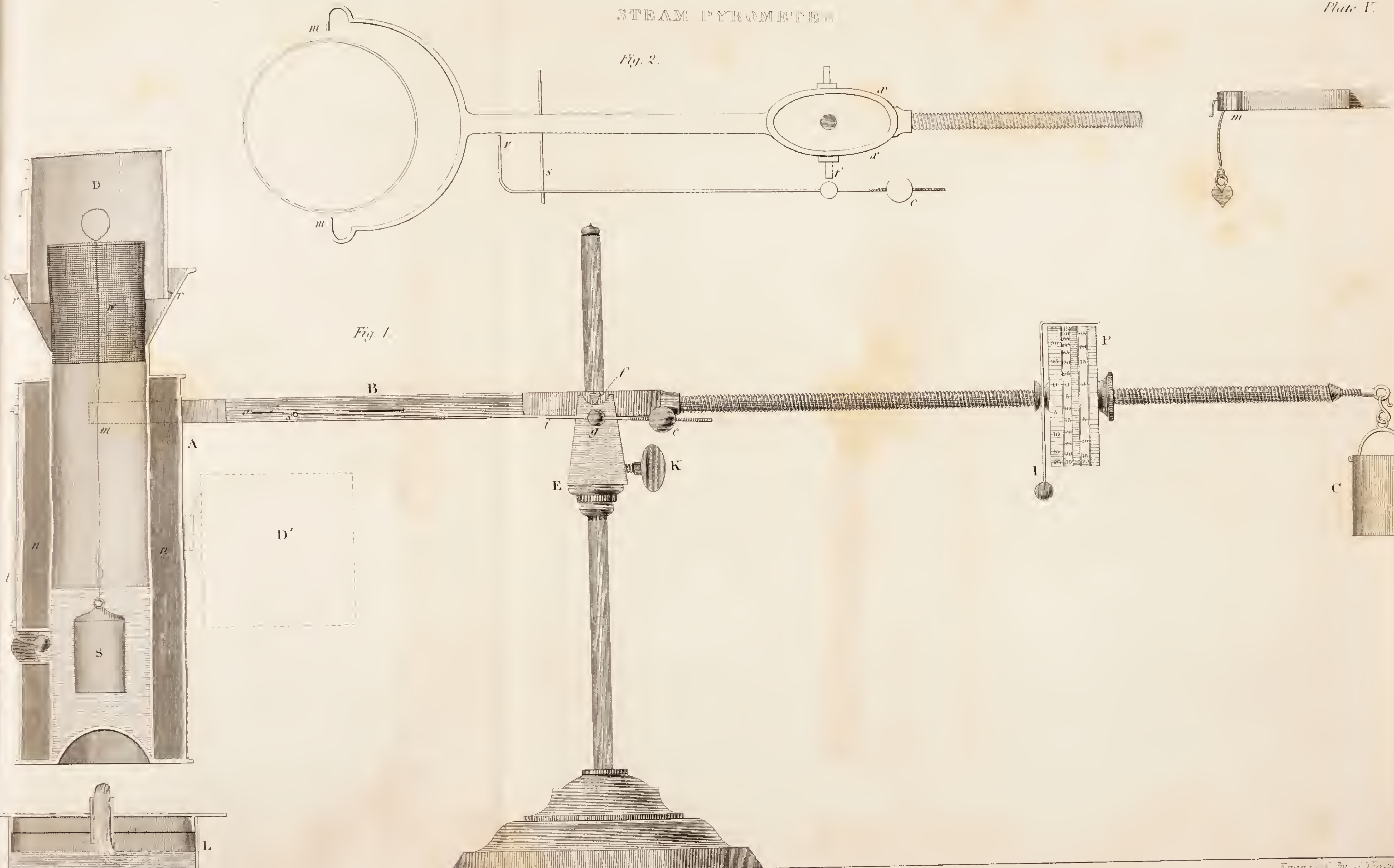
Thus if L be the length of the arm from f to m where the boiler is suspended, and n=the number of threads of screw on an equal length of the opposite arm; then will $\frac{L}{n}$=the length of a thread.

Putting P=the weight of the counterpoise,

and v=the weight of vapour which must escape in order that an equilibrium, destroyed by its loss, should be restored by making P move one revolution, that is one thread nearer to f, we shall have $\frac{L}{n} : L :: v : P$ or $\frac{PL}{n}=Lv$; whence $v=\frac{P}{n}$. This may be termed the *mechanical relation* of the instrument to the vapour produced.

To determine the *physical action* of the standard piece, if z be supposed=its specific heat; l= the latent heat of vapour from the liquid at its boiling point; i= the weight of the standard piece (expressed in the same denomination as that of P); t= the number of degrees to be placed on the circumference of the revolving weight; P=the degrees belonging to the same scale as those in which l is expressed; and v= (as before,) the weight of vapour counterpoised by a single revolution of P; then the efficient cause of vaporization while the standard piece cools through t degrees, will be represented by itz, and the *effect* produced must be expressed by vl; Hence is derived the equation $lv=itz$, or $v=\frac{itz}{l}$. Comparing this value of v with that obtained above, we get $\frac{P}{n}=\frac{itz}{l}$. Hence the weight of the standard piece $=i=\frac{Pl}{ntz}$, and the five following formulas will give *either one* of the other quantities, when the rest are assigned, viz. $P=\frac{nitz}{l}$; $z=\frac{Pl}{nit}$; $n=\frac{Pl}{itz}$; $t=\frac{Pl}{niz}$, and $l=\frac{nitz}{P}$. In practice it was found most convenient to make $t=100°$ Fah. But by assuming t equal to the distance *between the freezing and the boiling point of water* under mean atmospheric pressure, a single standard piece would be sufficient to render the instrument universal in its indications. The curved surface of the revolving weight would only require to be divided into as many separate bands as there were different scales to be placed upon it, and graduating each band into as many equal parts as the particular scale comprehends degrees between the two

STEAM PYROMETER



Wm Mason Del.

Engraved by J. Yeager

The standard piece employed to produce vapour after having been heated in the bath of melted metal surrounding the bar under trial, was formed of wrought iron of the figure seen at S, its greatest length $2\frac{3}{4}$ inches, its diameter one and $\frac{1}{16}$ inch and its weight 6336 grains Troy. This was suspended by an iron wire $\frac{1}{50}$ of an inch in diameter to the centre of a wire-gauze cap *w*, the lower and smaller end of which, entered the mouth of the boiler A, at the base of the funnel *r*. The upper diameter of this cap is $2\frac{1}{2}$ inches and its height $2\frac{3}{4}$ inches, giving an area, including the top and sides, of more than $13\frac{1}{2}$ square inches, or more than three times as much as the section of the boiler at its mouth. The object of employing this cap is to prevent the dashing out of water by ebullition—an effect which is, however, only liable to happen near the close of an experiment when the iron has descended to the temperature of *maximum vaporization*,* and when the boiler contains too much water.

The Condenser.

In order to prevent all escape of vapour after ebullition has ceased, a cylindrical cap of tinned iron D, is placed over that of wire gauze, the instant that the boiling point is attained. In general, this cap is kept suspended at one side of the boiler A, as exhibited in outline at D′. The lower rim of the condenser is furnished with an exterior welt or hem of silk, sewed to the tin by means of fine punctures near its edge. This serves effectually to prevent the escape of steam, and, besides allowing the operator to attend deliberately to the adjustment of the counterpoise, will admit, when necessary, the postponement of this process for a considerable length of time. The counterweight *c*, is to balance the standard piece S, with its suspending wire, and the wire-gauze cap W. As long as the water is kept boiling by the action of the lamp L, C is removed from the beam and is replaced only after the condenser has been transferred from D′ to D. The support E of the beam may be elevated or depressed on its sustaining rod by means of the tightening screw K. Immediately below the fulcrum *f*, is a small hole drilled horizontally into E, to receive a brass tap carrying a ball $\frac{3}{8}$ of an inch in diameter, through which passes the small index-wire *i*, so adjusted by means of the screwed counter weight *c*, as to be accurately balanced on the tap *g*, as an axis on which it turns with no other resistance than what is due to the friction produced by its own weight.

Near the extremity *v* of this wire, it is bent at right angles, and the pointed extremity directed to the side of the beam where, at *o*, is a straight line $\frac{3}{4}$ of an inch long, serving to guide the eye in reproducing the level after an experiment. A little below this line, is a transverse hole through the beam, in which slides the register *s* (Figs. 1 and 2,)—a wire about $\frac{1}{16}$ of an inch in diameter, and $2\frac{1}{2}$ inches long. While the water in A is kept boiling by means of the lamp, the boiler continues to rise, and as the register now projects out beyond the index *i*, it lifts the latter, keeping the point *v* always directed a very little above the line *o*. But when W has been inserted in its place, with S suspended in the water, the additional weight, destroying the equilibrium, depresses the boiler, the base of which rests on

points above mentioned. Thus we should have on the band marked Reaumer, 80 degrees; Centigrade, 100°; Delisle, 150°; and Fahrenheit 180.° It may not be improper to remark that in applying the above formulas, the numerical value of *l* must also vary with the thermometrical scale. Thus if for Fah. it be 1037° it will be for Centigrade, $576\frac{1}{9}$; for Delisle, $863\frac{4}{7}$, and for Reaumer $460\frac{8}{9}$.

*See Amer. Journal of Science, vol. 21, p. 304.

the flat surface of the lamp L, the concavity in the bottom serving as an extinguisher to the flame. The index i, is, in the mean, time left at the level attained by the register at the moment before the immersion. While ebullition is proceeding, the operator pushes back the register so as to project but little from the interior side of the beam; then observing the thermometer t, takes the condenser from the position D′, and, at the instant the ebullition ceases, covers the boiler with it, as at D, letting the standard piece remain in place; and having attached the counterpoise C, proceeds to bring down the boiler end of the beam, (which at first rises above the index i,) by causing P to revolve in the direction towards f.

The number of revolutions being counted so many hundreds of degrees, he has only to add to their number 212°, in order to obtain at once the temperature by Fahrenheit's scale.

As both the latent heat of vapour and the specific heat of iron enter into the calculation, in constructing the steam pyrometer, and as on both these points considerable discrepancy prevailed among writers who had treated of these subjects, it was thought important to attempt a direct solution of the question as presented in the particular case of this investigation.

Two methods offered themselves, of verifying the calculations respecting the instrument. The first was, to heat the standard piece to any known temperature above 212°, and in that state plunging it into the boiling water to ascertain whether the amount of water vaporized weighed as many parts measured by hundredths of a revolution of C, as the standard piece had been heated in degrees above the boiling point.

This method being the most direct, was first resorted to by the committee.

As the standard piece S, was at first made one or two hundred grains heavier than was supposed to be necessary, trial was made in the way just indicated, and as an excess of vapour was found to have been obtained, the standard piece was proportionally reduced in weight to that which has been already stated.

The other method consisted in determining separately by direct experiment, both the latent heat of vapour, and the specific heat of the standard piece. The researches on these subjects were made in the manner and with apparatus described below.

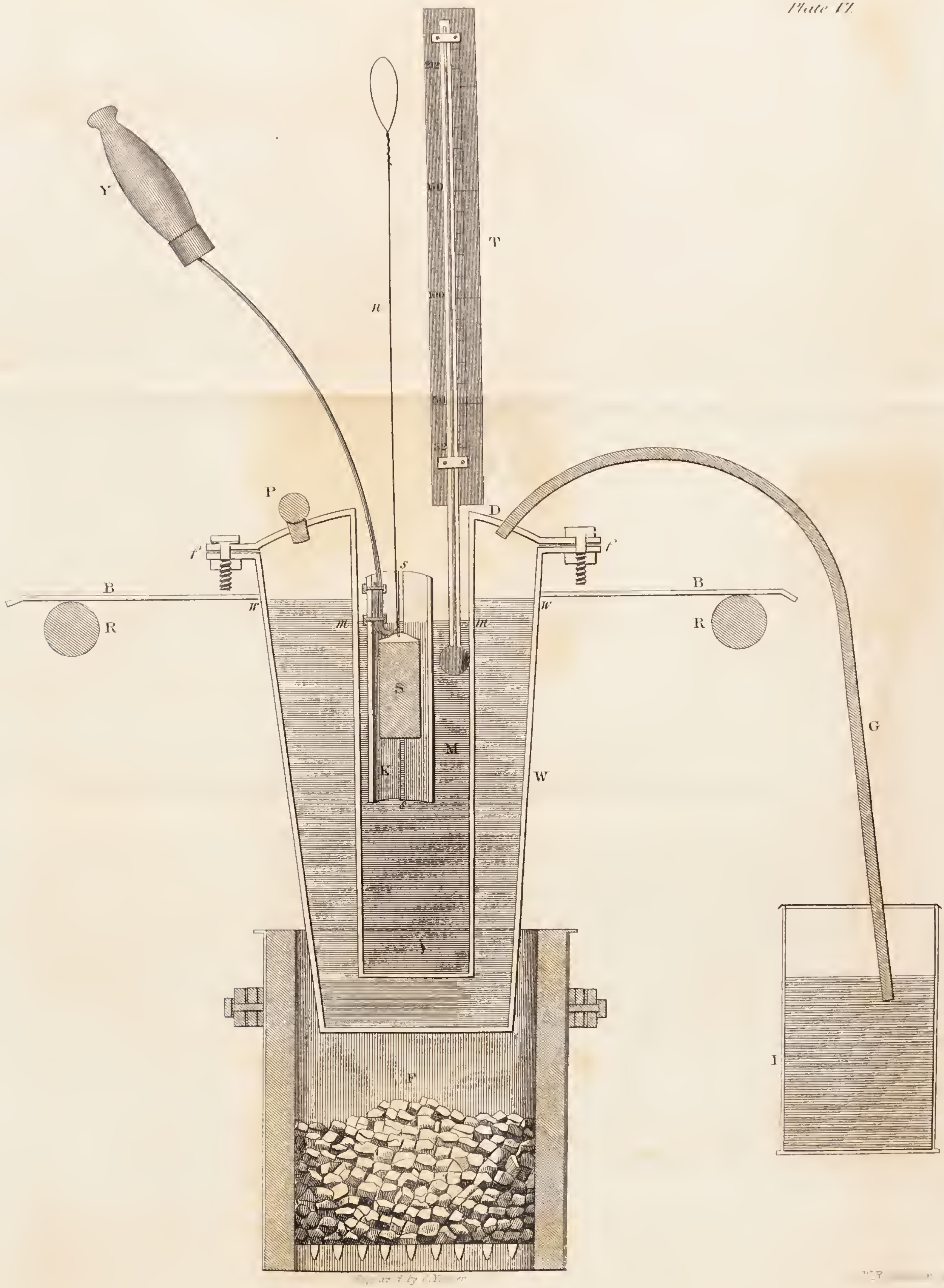
Specific heat of iron.

In determining the specific heat of the standard piece of the steam pyrometer it was deemed adviseable to employ processes somewhat independent of each other, and especially to vary the circumstances of the experiments, so that if possible the discordances on this subject might be reconciled, or at least referred to their probable origin. The first step was to ascertain the specific heat of the standard piece from 212° to the ordinary temperature of the atmosphere.

Bath for heating the standard piece.

The apparatus for this purpose is represented in plates VI. and VII. In plate VI. is seen a vertical section of the apparatus in which the iron standard piece S was heated. W is a cast iron vessel in the form of a frustum of a cone, 12 inches high, 7 inches in diameter at top, and 5 at the bottom; the upper edge being furnished with a flanch to match a corresponding flanch on a cover D, which was turned to fit it, and to form with it a steam tight joint as at $f,f,$. In the central part of this cover is the mouth of another vessel or tube M, $2\frac{1}{2}$ inches in diameter, the bottom of which is about $\frac{1}{2}$ an inch

Plate 17.




A
B
C
D
S
212
200
150
100
50
30
32
115
110
100
90
80
70
60
50
74
60
50
40
34

above the bottom of W. The space between the outside of the tube M and the inside of W, is nearly filled with water, as seen at w, w, introduced by an aperture ordinarily closed by the iron stopper P. The interior of M is filled to about the level m, m, with mercury.

In the cover D on the side opposite to P, is another aperture into which is fitted by grinding, an iron tube G, to receive and convey away to a water vessel I, the excess of vapour generated in W. The vessel thus constructed is placed in a circular opening in a sheet iron plate, B B, 14 inches square, which rests on two guide rods R, R, of the frame of the machine. (Plate, 1.)

F is the furnace already described, as applied to the purpose of heating the bars of iron. X is a sheet iron cylindrical case, $\frac{1}{8}$ of an inch thick, open at both ends, and having along one side, a slit *s s*, $\frac{1}{16}$ of an inch wide left for the purpose of permitting the wire n, by which the standard piece S is suspended, to be introduced or withdrawn laterally, while the loop at its top is held by one hand of the operator; and by the other, the handle Y. The rod which carries this handle is fastened by rivetting to the inside of the case K, and below the rivets the point is turned inward toward the centre of the case, preventing the iron cylinder S from rising above that point. This gives the operator entire command of the latter, notwithstanding the buoyancy of the mercury.

The thermometer T, graduated above the boiling point of water, was placed with its bulb on a level with the centre of S.

By raising or lowering the furnace F, the ebullition was maintained at a nearly uniform rate during the time of several consecutive experiments.

When the mercury in T was found to be stationary at 212°, the shield K was withdrawn from the mercurial bath ; the operator held Y in one hand, while the other supported the wire n; and in this manner without allowing S to come in contact with the air, conveyed it to the mouth of the water vessel of the cooling apparatus, where K was held in a vertical position, and the wire quickly lowered till the standard piece was immersed, when the shield was immediately removed, the wire escaping through the slit *s s*.

The cooling apparatus.

The arrangement of parts in the cooling apparatus, is seen in plate VII., where A is the cylindrical containing vessel, filled with water to such a height as to be completely full, when the standard piece S, and the bulb of thermometer t are immersed.

B is a cylindrical vessel of tinned iron, 14½ inches high, and 9 inches in diameter, to which is adapted the cover D of the same material, having in the middle a circular aperture *a a*, 3 inches in diameter, for receiving the thermometer t, and the standard piece S ; allowing likewise sufficient space to move the suspending wire and thermometer. Another aperture through D, near its circumference, admits the lower part of the thermometer i, and an opening near the bottom of B, receives the bulb of the thermometer l.

The thermometer O was suspended just without the vessel B, to mark the temperature of the room. C is a support for the water vessel A, formed of a cylindrical block of charcoal, 4 inches high.

The method of adjusting the weight of water in A, in this series of experiments, was the same as that subsequently described in the experiments on the latent heat of vapour, except, that in the present case, no process of weighing was required, after the heating had been performed.

The exact adjustment of the quantity of water to be used in every repetition of a given series, was made by means of a tube, of small dimensions, open

at both ends; by the aid of which it was easy to add or to remove minute quantities of liquid to render the balance true.

Thermometer in the Water Vessel.

The most important of the thermometers used in this part of the investigation was that marked *t*, but which was in fact the thermometer A, elsewhere referred to, the bulb of which was $7\frac{1}{4}$ inches long, intended to reach from the top to the bottom of the liquid, and which, it actually did in some of the containing vessels, with which it was used. Its diameter was about $\frac{3}{4}$ of an inch. The glass constituting the bulb of this thermometer weighed 433.85 grains, as ascertained by actual weighing, after the instrument had been broken. It was filled after the elongated bulb had been joined to its stem, and the separate weight of these ascertained. The mercury precisely filled the bulb alone at 32°, and the weight of mercury required for this purpose was found to be 4682 grains. As most of the experiments with this instrument were made with an initial temperature about 62°, it has not been deemed necessary to make more than one correction for the quantity of mercury expelled from the bulb, or excluded from the influence of the water vessel. At 62° the bulb must have held, by calculation,* 4670 grains of mercury, which by a mean of several determinations already published, possesses a specific heat of .0327, and gives an equivalent in grains of water, of 152.7.

When this thermometer was used in connexion with a containing vessel of glass, the weight of its bulb was added to that of the vessel; and in other cases, the specific heat attributed to it, was that obtained by means of several trials of it with glasses of different thicknesses instituted with a view to determine the effect of that material, towards cooling the heated body or standard piece. The specific heat thus found was .10036, according to which the bulb would be equivalent to 43.45 grains of water. The length of the scale of this thermometer was 37 inches, and the graduation extended from 34° to 74°; so that each degree was nearly $\frac{37}{40}$ of an inch in length and the degrees were divided each into 50 parts, each part being of such magnitude that the eye could, when necessary, easily subdivide and read them into hundredths.

The graduation of this thermometer was obtained by direct comparison with a well tried standard instrument, the degrees of which were about $\frac{1}{4}$ of an inch in length. For this purpose, the bulbs of both were immersed in a large quantity of water contained in a Hessian crucible, surrounded by another of black lead; thus affording a combined mass which changed its temperature with extreme slowness, and enabled us to mark with deliberation and accuracy every degree on the long scale, after having for some time agitated the two in contact with each other and tempered the water to the point required.

The general mode of operating with the apparatus, plate VII., was, after giving the water vessel and thermometer *t*, a temperature a few degress below that of the surrounding air, to take simultaneous observations of all the thermometers which were recorded by one assistant, while another person

* Petit and Dulong, found the expansion of *mercury in glass* between 32° and 212,° to be $\frac{1}{63.8}$ consequently its expansion for 1° s $\frac{1}{180\times 63.8}=\frac{1}{11484}$, and for (62°—32°)= 30°, it will be $\frac{30}{11184}$ of its bulk at 32°. But $4682\times\frac{30}{11484}=$ 12.2 grains and 4682 — 12 = 4670 as above stated.

bringing the hot standard piece, surrounded by its shield, from a distance of about 4 feet out of the heating apparatus (Plate VI.) immersed and held it suspended, as already described. The moment of immersion was observed by a second assistant, on a time-keeper marking seconds. The manipulatoı continually moving the thermometer t, and the standard-piece about in the water, read off the degrees and parts as successively attained by the mercury, while the second asssistant noted, and the first recorded them, together with the time of each observation.

The method just described, afforded the means of determining approximately, the proper temperature below that of the air, at which the water ought to be, when the standard-piece was immersed, in order that the heating and the cooling power of the atmosphere should be equal to each other. Table XIV. will be found to contain a synopsis of the experiments conducted in this mannner with reference to different containing vessels. Some trials were made to ascertain, with different vessels, the rate at which the air alone, would, under given circumstances, produce certain elevations or depressions of temperature. But the interference of extraneous causes, such as the presence or absence of a stove in the apartment, the heat derived from the person of the observer, and others near the scene of the experiment, made it evident that a good defence against the influence of the air would be a better guarantee against error, from that source, than any table of corrections which could be constructed amidst so many modifying causes.

The results of a series of trials made in part without employing the vessel B to defend the water from the air and from radiation, are exhibited in Table IV. Some attempts were made, as above referred to, towards the correction of the irregularities therein observed; but the uncertainty attending the process, induced the committee to prefer, when practicable, the *prevention*, to the *correction* of these anomalies. As the vessel B held $924\frac{1}{2}$ cubic inches, the whole quantity of air it could contain did not exceed $277\frac{1}{2}$ grains; which, supposing the specific heat of air to be .26, would not be equivalent to more than 72 grains of water, but as a considerable portion, amounting to at least $\frac{1}{7}$ of the whole, was occupied by the water vessel and its support, the remaining air could in no instance have been equivalent to more than 62 grains of water, and as the greatest change which occurred in the temperature of this portion of air during any experiment, was but 1.7°, and as the mean of all the changes of this kind observed during the progress of the investigation, was a gain of 0.325°, while the correspondent mean gain of temperature in the water was 7.26°, and the mean weight of the latter 13.100 grains, it is evident that the relative influence of the air and of the water will be represented by 62 grains $\times$ 0.325° = 20.15 and 13100 grains $\times$ 7.26° = 95106, or the former is $\frac{1}{4720}$ part of the latter, from which it appears that from this cause the expression for the specific heat could not have been affected under the fifth place of decimals.

In a series of 13 trials in which the water, amounting to about 40,000 grains, was contained in copper vessels, (Table VIII.) and the rise of temperature in the same was at a mean about 2.5° the air gained about .292 of a degree, which would indicate that the cooling power of the air confined in the vessel B, compared with that of the water in A was but as 1 to 5550, a result which would still less affect the general correctness of the determination.

[*The reader will please to observe that many of the following Tables extend each over two opposite pages.*]

TABLE IV. *Experiments to determine the specific heat of the wrought iron standard piece used in experiments with the steam pyrometer employed in this investigation, the water being contained in a thin glass cylindrical jar, weighing 3325 grains, and*

No. of experiment.	Date.	Temperature.	Temperature of the water at the beginning.	Temperature of the water at the end.	Gain of temperature by the water.	Loss of temperature by the iron.	Time taken up by the experiment.	Weight of water in the jar.	Equivalent of vessel in grs. of water.	Equivalent of thermometer in water.
		°	°	°	°	°		grs.	grs.	grs.
1	1834. Nov. 22.	69.	64.5	69.8	5.3	142.2	480″	19177.8	339	140.
2	Dec. 6.	65.5	59.5	64.8	5.3	147.2	400	19788.1	329	143.3
3	"	69.	61.2	66.5	5.3	145.5	300	19788.1	339	143.3
4	"	70.5	64.15	69.2	5.05	142.8	210	19788.1	339	143.3
5	"	73.5	58.4	63.9	5.5	148.3	180	19788.1	339	143.3
6	Dec. 8.	74.5	65.1	70.2	5.1	141.8	200	19788.1	339	143.3
				correc. 69.76	correc. 4.66	correc. 142.24				
7	"	72.5	71.6	76.6	5.1	135.4	200	19788.1	339	143.3
8	"	73.5	69.15	74.4	5.25	137.6	240	19788.1	339	143.3
				correc. 74.02	correc. 4.87	correc. 137.98				
9	"	72.	64.8	69.9	5.1	142.1	210	19788.1	339	143.3
10	"	75.	70.95	75.8	4.85	136.2	210	19788.1	339	143.3
11	"	76.	70.	75.1	5.1	136.9	240	19788.1	339	143.3
12	Dec. 29.	62.	61.9	67.	5.1	145.	240	20050.	339	43.4
13	"	65.	59.8	64.8	5.	147.2	180	20050.	339	43.4
14	1835. Jan. 3.	65.	60.	65.	5.	147.	180	20050.	339	43.4
15		66.	59.75	64.55	4.8	147.45	180	20050.	339	43.4
16	"	66.	59.6	64.50	4.9	147.5	180	20050.	339	43.4
17	"	65.	59.6	64.40	4.8	147.6	240	20050.	339	43.4
18	Jan. 10.	63.	65.2	69.8	4.6	142.2	152	20050.	339	43.4
19	"	62.2	65.2	69.8	4.6	142.2	154	20050.	339	43.4
20	Jan. 17.	71.	66.	70.7	4.7	141.3	272	20050.	339	43.4
21	"	68.	63.3	68.15	4.85	143.85	194	20050.	339	43.4
22	"	61.9	54.5	59.8	5.3	152.2	119	20050,	339	43.4
23	"	63.5	60.	64.9	4.9	147.1	149	20050.	339	43.4
24	Jan. 24.	63.5	64.9	69.5	4.6	142.5	96	20050.	339	43.4
25	"	71.	67.1	71.8	4.7	140.2	145	20050.	339	43.4
26	"	71.	67.1	71.8	4.7	140.2	153	20050.	339	43.4

TABLE IV.] *capable of containing, in addition to the thermometer and standard piece, about* 20,000 *grains of water. The iron was heated in a bath of mercury surrounded by boiling water, giving it a temperature of* 212° *at the time of each immersion.*

Weight of water and equivalent of glass and thermom.	Loss of temperature X weight of metal.	Gain of temperature X weight of water.	Specific heat by the uncorrected data.	REMARKS.
19656.8	853200	104181.04	.12210	Using for specific heat of glass, the result obtained by 10 comparisons, viz. .101911, we have the equivalent of the *container* in this series=339 grains.
20270.4	883200	107433.12	.12164	Began too low.
20270.4	873000	107433.12	.12306	Water gained heat from the air the whole time of this experiment.
20270.4	856800	102365.52	.11947	Final temperature much too low.
20270.4	889800	111487.2	.12529	Do. much more so.
20270.4	850800	103379.04	.12150	The correction here made is from observing that ,at the initial temperature 45″ were required for the air to heat the water .1 of a degree. This gives sp. ht.=11.068.
20270.4	812400	101352.	.12475	Exposed to radiation from the stove, gained .1° in 40,″ when air was 73, water 70.4. Corrected result =.11068.
20270.4	825600	106420.2	.12890	Gained from the air, and from radiation, .05° in 25″, or 0.38° in 240″, leaving the corrected gain 4.87. Corrected result =.11924.
20270.4	852600	103379.04	.12124	Began and ended below the temperature of the room; result considerably too high.
20270.4	817200	983114.4	.12018	Ended very near the temperature of the room; result too high.
20270.4	821400	103579.04	.12549	Ended below the temperature of the room.
20432.4	870000	104205.24	.11977	Began at the temperature of the room—stove in action.
20432.4	883200	102162.	.11567	Ended below temp. of room ; result too high.
				Mean of 13 preceding results=.123004.
20432.4	882000	102162.	.11583	Ended at temp. of room. Now shielded the water vessel with a conical tin cover, with an opening to admit the thermometer.
20432.4	884700	98075.52	.11081	Shielded as above.
20432 4	885000	100118.76	.11313	Ended below temp. of the external air in room, but the shield was probably lower.
20432.4	885600	98075.52	.11074	Do. do.
20423.4	853200	93989.04	.11016	Began 2.2° and ended 6.8° above the temperature of the air; result too low.
20423.4	853200	93989.04	.11016	Began 3° and ended 7.6° above the air; too low, as before.
20432.4	847800	96032.28	.11327	Air in shield probably lower than without.
20432.4	863100	99197.14	.11493	Began 4.7° *below*, & ended 8.15° ab. the air.
20432.4	913200	108291.72	.11858	Ended 2.1° below the temp. of the air. Result consequently much too high.
20432.4	882600	100118.76	.11343	Begun 3.5° below, and ended 1.4° above the air ; a very fair experiment.
20432.4	855000	93989.04	.10991	Began 1.4° and ended 6° above the air ; result much too low.
20432.4	842400	96032.8	.11399	Began 3.9° below, and ended 0.8° above the air, received heat a little too long; result, a trifle too high.
20432.4	842400	96032.28	.11399	This experiment conformed in conditions precisely to the preceding, and the result is reproduced. [Mean of last 13=.11294.]

TABLE V.

Experiments to determine the spcific heat of the iron Standard-piece used in Experiments with the Steam Pyrometer employed in this investigation. The heating being performed in a bath of mercury surrounded with boiling water, and the cooling in a

No. of Experim't.	DATE.	Temp. of the air in the room at the beginning.	Temp. of the air at the end of the experiment.	Temp. of air inside of shield at beginning.	Temperature of the air inside at the end.	Evap. point of air.	Temperature of the water at the commencement.	Temperature of the water at the end.	Temperature gained by the water.	Temperature lost by the iron.	Time elapsed during the exper't.	Weight of water used.
	1835.											
1	Feb. 28,	58.75	59.			48	52.62	58.105	5°.495	153°.895	313''	16728.75
2	"	57.	58.25			48	56.09	61.71	5.62	150.29	260	16728.75
3	"	57.75	—			48	52.33	57.83	5.50	154.17	319	16728.75
4	"	53.	55.5			48	49.35	55.28	5.93	156.72	135	16728.75
5	Apl. 7,	67.1	68.5			49	63.50	68.94	5.44	143.06	177	16494.5
6	"	67.1	67.7			49	63.52	68.97	5.45	143.03	unc	16494.5
7	"	67.15	66.70			50	63.50	68.90	5.4	143.1	unc	16494.5
8	"	67.1	67.58			50	63.50	68.90	5.4	143.1		16494.5
9	Apl. 18,	58.	58.	55.	55.25	51	53.3	59.09	5.79	152.91		16494.5
10	"	60.	60.5	56.	56.5	51	52.46	58.34	5.88	153.66		16494.5
11	"	62.	62.	58.25	58.5	51	51.3	57.28	5.98	154.72		16494.5
12	"	57.	57.	53.5	53.5	51	46.7	52.92	6.22	159.28		16494.5
13	Mar. 28,	66.	66.	64.	64.4		60.	65.49	5.49	149.51		16494.5
14	"	66.	66.	65.2	65.2		60.	65.51	5.51	146.49		16494.5

TABLE V.

glass cylindrical jar, weighing 12272 *grains, and receiving such a quantity of water at each experiment as completely to fill the jar when the thermometer and the iron were immersed. Weight of Standard-piece* 6000 *grains. Temperature at immersion* 212°.

Liquid in therm. in grs. of its equivalent of water.	Total weight of glass in grains including that of the therm. bulb.	Equivalent of glass in grains of water.	Total equivalent of water heated.	Weight of iron X its loss of temperature.	Weight of total equivalent of water X its gain of temperature.	Specific heat of iron.	REMARKS.
91	12536	1391.5	18210.	923370	99881.85	.10817	This and the three following experiments were made with the water beginning at temperatures corresponding to those of a series of the same number, made in a thin glass vessel, having precisely the same capacity as the one now used.
91	12536	1391.5	18210.	901740	102340.2	.11348	The thermometer here used is the long-bulb spirit instrument C, the specific heat of which is only approximately estimated, the glass at 264 grains, and the alcohol at 242.
91	12536	1391.5	18210.	925020	100155.	.10827	
91	12536	1391.5	18210.	940320	107985.3	.11482	This experiment began and ended below the temperature of the air. The result is consequently too high.
152.7	12706	1275.2	17922.4	858360	97497.856	.11358	This and the three following were made by the aid of thermometer A, having a bulb 7 1-2 inches long, containing at 62° 4670 grains of mercury.
152.7	12706	1275.2	17922.4	858380	97677.08	.11382	These three experiments were intended to coincide with two others made in a series with the thin glass jar; the mean of these three is .11312, that of the other set .11347.
152.7	12706	1275.2	17922.4	858680	96780.96	.11272	
152.7	12706	1275.2	17922.4	858600	96780.96	.11272	
152.7	12706	1275.2	17922.4	917460	103770.696	.11310	The four following coincide nearly with three others made in a series with the thin glass of the same capacity. These several comparative portions of the two series were made with a view of obtaining from them the specific heat of glass. Weight of glass bulb of thermometer A, was carefully ascertained after it had been broken, & found to be 433.85 grains. To avoid fractions, it is here taken at 434. The weight of mercury determined by weighing at the time of filling the instrument.
152.7	12706	1275.2	17922.4	921960	105383.712	.11430	
152.7	12706	1275.2	17922.4	928320	107175.952	.11545 too high	
152.7	12706	1275.2	17922.4	955680	111477.328	.11560 too high	
152.7	12706	1275.2	17922.4	879060	98393.976	.11193	This and the following may furnish a comparison with the 10th experiment in the table of those made in the thin cylinder of the same capacity. By that comparison the specific heat of glass appeared to be .10036.
152.7	12706	1275.2	17922.4	878940	98952.424	.11235	
					Mean of 14	=.11288	These four are the greatest number which *conform* as far as to the third place.
					Mean of Nos. 2, 5, 6 and 9	=.11349	

TABLE VI.

TABLE VI.—*Experiments to determine the specific heat of the iron standard piece used in experiments with the steam pyrometer, employed in this investigation. The heating being performed in a bath of mercury, surrounded with boiling water, and cylindrical jar, weighing 2996 grains, receiving such quantities of water, at each ex-*

No. of experi.	DATE.	Temp. of air at beginning.	Temp. of air at the end.	Temp. within the tin cylinder at the beginning.	Temperature in the cylinder at the end.	Evapo. point.	Temperature of the water at beginning.	Temperature of the water at the end.	Temperature gained by the water.	Temperature lost by the iron.	Time elap. during the exp.	Weight of water used.
		°	°	°	°	°	°	°	T′ °	t′ °		W. grs.
1	1835. Feb. 21,	57.5	58.			50	56.09	61.95	5.86	150.35	185″	16728.
2	"	58.5	59.			51	52.62	58.70	6.08	153.3	325	16728.
3	"	57.	57.5			47	52.33	58.11	5.78	153.89	309	16728.
4	"	56.5	56.5			47	49.35	55.66	6.31	156.34	464	16728.
5	April 7,	57.2	67.5			49	63.51	69.22	5.71	142.78	154	16494.5
6	"	67.1	68.2			49	63.50	69.26	5.76	142.74	157	16494.5
7	Aprll 18,	60.	60.	56.75	57.25	52	53.43	59.58	6.15	152.42		16494.5
8	"	60.	59.	57.75	57.5	53	52.46	58.64	6.18	153.36		16494.5
9	"	62.5	63.	59.25	59.2	53	51.44	57.76	6.32	154.24		16494.5
10	Marh. 28.	65.	65.	63.	63.6		60.	65.79	5.79	146.21		16494.5

TABLE VI.

periment, as completely to fill the jar when the thermometer and the iron were immersed. Weight of the standard piece, 6000 grains,—temperature at immersion, 212.° Weight of glass container and of thermometer bulb 3250 grains.

Equivalent of liquid in the ther. in grains of water.	Equivalent of glass in grains of water.	Total equivalent of water heated.	Weigh of iron × its loss of temperature.	Weight of equivalents of water × its gain of temperature.	Specific heat of iron.	REMARKS.
e. grs.		grs.				
91.	360.7	17179.7	90210	100674.8	.11160	The first four experiments were performed with a thermometer of spirits of wine, the degrees of which were divided into 100ths, but the performance of instruments of this sort being liable to inaccuracy from the different quantities of liquid taken up at different times in wetting the interior of the tube, the confidence reposed in these results is less than in those of the series with the mercurial therm. (A).
91.	360.7	17179.7	919800	104454.4	.11356	
91.	360.7	17179.7	923340	99300.4	.10754	The 3d exp. of this table with the 3d of the preceding table gives for specific heat of glass .09651.
91.	360.7	17179.7	938040	108405.8	.11556	As the whole process was performed below the temperature of the air, this result must obviously be too high, compared with exp. 4 of preceding table, this gives spec. heat of glass. 12317.
132.7	300.6	16947.8	856680	96771.938	.11296	This experiment compared with experiments 7 and 8 of the preceding series give for specific heat of glass .110202.
152.7	300.6	16947.8	856440	97619.328	.11398	This experiment compared with No. 6 of preceding table, gives for specific heat of glass, .11100, but compared with Nos. 7 and 8 it gives .130156.
152.7	300.6	16947.8	914520	104228.91	.11397	Compared with experiment 9 of the preceding table, this trial gives for an approximate specific heat of glass, .12662.
152.7	300.6	16947.8	920160	104737.404	.11405	With experiment 10 of preceding table this gives .09715 for specific heat of glass.
152.7	300.6	16947.8	915440	107110.095	.11574	This experiment was both begun and ended below the temperature of the air. The result must consequently be too high. Compared with experiment 11 preceding table, it gives specific heat of glass .110404.
152.5	300.6	16947.8	877260	98127.762	.11185	Specific heat of glass derived from a comparison of this experiment with Nos. 13 and 14 of the series in the thick jar is .10036. Mean sp. ht. of glass .111063.

TABLE VII.

Experiments to determine the specific heat of the iron standard piece used in experiments with the steam pyrometer employed in this investigation. The heating being performed in a bath of mercury surrounded with boiling water, and the cooling in two different glass vessels in the two divisions of the series, the heavier weighing 6923,

No. of experim.	DATE.	Temp. *outside* the cylinder at the beginning.	Temperature outside at the end.	Temp. *inside* of tin cylinder at the beginning.	Temp. inside at the end.	Temperature of water at the beginning.	Temperature of water at the end.	Gain of temp. by the water.	Loss of temperature by the iron.	Time occupied by the experim.	Weight of water used in grains.	Equiv. of mercury in the thermometer, in grains of water
		°	°	°	°	°	°	T °	t °	"	w	e
1	1835. Mar. 16.	65	65.5			60.5	68.66	8.16	143.34		10872	152.7
2	"	64.8	65.			60.5	68.74	8.24	143.26		10872	152.7
3	"	65.7	65.8			60.5	68.72	8.22	143.28		10872	152.7
4	April 4.	67.	68.	65.2	65.7	60.	68.36	8.36	143.64	137"	10800	152.7
5	"	67.	66.	65.	65.3	60.02	68.27	8.25	143.73	141	10800	152.7
6	"	65.75	66.25	65.	65.3	60.01	68.38	8.37	143.62	125	10800	152.7
								T′	t′		w	e
7	Mar. 16.	65.6	65.9			60.5	68.88	8.38	143.12		10872	152.7
8	"	65.5	65.8			60.5	69.	8.50	143.		10872	152.7
9	"	65.3	65.4			60.5	69.	8.50	143.		10872	152.7
10	April 4.	66.25	66.25	66.1	66.3	60.	68.56	8.56	143.44	170	10800	152.7
11	"	66.	66.1	65.2	65.5	60.	68.68	8.68	143.32		10800	152.7
12	"	66.5	66.5	65.9	66.1	60.	68.68	8.68	143.32		10800	152.7

TABLE VII.

and the lighter 2465 grains, receiving equal quantities of water, so as accurately to fill them when the standard piece and the thermometer were immersed. Weight of the standard-piece 6000 grains; its temperature at immersion, 212°.

Weight of glass in the containing vessel and thermometer bulb.	Equivalent of the containing vessel in water.	Amount of matter heated.	Weight of iron X loss of temperature.	Water X its gain of temperature.	Specific heat of iron.	REMARKS.
g	grs.	grs.				Thicker glass jar. The first three of these experiments were made under the tin cone, the next three within the tin cylinder with the cover affixed. The cone could not altogether prevent the circulation of air around the containing vessel.
7356 =433+6923	740.16	11764.8	860040	96001.584	.111624	
7356	740.16	11764.8	859560	96941.952	.112780	The mean result of 2d and 3d experiments may be compared with the identical results of the 8th and 9th, and the formula for that comparison is $\frac{(T't-Tt').(w+e)}{Tt'g-T'tg'}=x$ the specific heat of glass of this description.
7356	740.16	11764.8	859680	96706.656	.112244	
7356	740.16	11692.9	861780	97811.004	.113498	The mean result of the 4th and 6th experiments may in like manner be compared with the identical results of the 11th and 12th.
7356	740.16	11692.9	862380	96466.425	.111860	
7356	740.16	11692.9	861780	97811.004	.113498	
g' 2898 2465+=433	290.59	11315.3	858720	94822.214	.110422	Thinner glass jar. The 7th, 8th and 9th experiments were made under the tin cone, and the 10th, 11th and 12th within the tin cylinder, the error of one-tenth of a degree is suspected to have occurred in the reading of the 7th experiment.
2898	290.50	11315.3	858000	96180.05	.112098	The equivalent for the containing vessel in this and the following experiment as derived from a comparison with the 2d and 3d experiments of this series, is 1254. 85,and this gives sp. ht. of iron .111743.
2898	290.59	11315.3	858000	96180.05	.112098	
2898	290.59	11315.3	860640	96242.648	.111816	
2898	290.59	11243.3	859920	97591.844	.113489	The equivalent for the container for this and the following experiment is derived by formula, from a comparison with experiments 4 and 6, by which the specific heat of glass appears to be .100620.
2898	290.59	11243.3	859920	97591.844	.113489	
					.112409	Comparing for the specific heat of glass we get from experiments 1 and 8 - .115040 4 and 11- .100082 5 and 10- .100004 6 and 11- .098884 4 &6 with 11 and 12- .100620 Mean .103086

TABLE VIII.

Experiments to determine the specific heat of the Iron Standard-piece used in experiments with the Steam Pyrometer employed in this investigation, the heating being performed in a bath of mercury surrounded with boiling water, the cooling in two

Number of the Experiments.	DATE.	Temperature of the air outside of the tin cylinder at beginning.	Temp. outside of the tin cylind. at the end.	Temperature within the cylinder at beginning.	Temperature within at the end of the experiment.	Temperature of the water at the commencement of the experiment.	Temperature of water at the end.	Gain of temperature by the water.	Loss of temperature by the iron.
		°	°	°	°	°	°	°	°
1	1835. May 2,	66.	66.5	65.2	62.7	49.62	52.60	2.98	159.40
2	"	66.25	67.	64.5	63.	53.70	56.54	2.84	155.46
3	"	66.	66.25	63.5	63.2	57.06	59.82	2.76	152.18
4	"	66.	66.5	63.8	64.1	60.22	62.84	2.62	149.16
5	"	66.	66.25	64.8	65.15	62.95	65.42	2.47	146.58
6	"	66.	66.	65.6	65.8	63.28	65.75	2.47	146.25
7	"	66.5	67.	66.2	66.6	65.78	68.31	2.53	143.69
8	1835. May 9,	67.	67.	66.9	66.9	63.88	66.34	2.46	145.66
9	"	66.5	67.	67.1	67.1	65.78	68.26	2.48	143.74
10	May 16,	64.	64.	62.2	61.4	51.80	54.54	2.74	157.46
11	"	64.	64.	61.4	61.2	55.00	57.67	2.67	154.33
12	"	64.25	64.5	61.9	62.1	58.09	60.72	2.63	151.28
13	"	65.	65.	62.8	63.	60.88	63.31	2.43	148.69
14	"	65.	65.	63.8	64.2	43.42	65.81	2.39	146.19
15	"	65.	65.	64.6	65.25	65.81	68.26	2.45	143.74
16	"	65.	65.	66.	66.5	68.20	70.64	2.44	141.36
17	"	65.	65.	67.	67.2	70.46	72.72	2.26	139.28
18	"	65.	65.	66.5	66.	63.28	65.66	2.38	146.34

TABLE VIII.

different copper vessels capable of receiving equal weights of water, but having different thicknesses. Weight of the Standard-piece at the time, 6000 *grains, and its temperature at immersion* 212°.

Weight of water employed.	Equivalent of the thermometer in grains of water.	Weight of the copper cylinder.	Equivalent of the containing vessel in grains of water.	Total matter heated.	Specific heat.	REMARKS.
grs.	grs.	grs.	grs.	grs.		
38659	196	5178	540	39395	.122169	The first three experiments were begun and ended so far below the temperature of the air, that the water must obviously have received heat from the latter during the whole time.
38659	196	5178	540	39395	.119380	
38659	196	5178	540	39395	.118504	
38659	196	5178	540	39395	.114784	
38659	196	5178	540	39395	.110100	
38659	196	5178	540	39395	.110366	Mean of the whole 7 experiments.=11595.
38659	196	5178	540	39395	.115061	Mean of the last 4.=11257.
38659	196	19738	2056.8	40911.8	.114411	This and the last six are considered *comparable.*
38659	196	19738	2056.8	40911.8	.118052	This and the three following give results varying from the rest, partly on account of an excess of heat which kept the steam in the heating apparatus a little too high.
38659	196	19738	2056.8	40911.8	.118676	
38659	196	19738	2056.8	40911.8	.117933	
38659	196	19738	2056.8	40911.8	.117407	
38659	196	19738	2056.8	40911.8	.111405	
38659	196	19738	2056.8	40911.8	.111318	
38659	196	19738	2056.8	40911.8	.114565	
38669	196	19738	2056.8	40911.8	.117661	
38659	196	19738	2056.8	40911.8	.110609	
38659	196	19738	2056.8	40911.8	.110869	This experiment with No. 6, gives by calculation the specific heat of copper .10431.
			Mean of all from 8 to 18=		.114990	
			Mean of 7 comparable=		.113261	

TABLE IX.

Experiments to determine the specific heat of the Iron Standard-piece used in experiments with the Steam Pyrometer. The heating being performed in the bath of mercury surrounded with boiling water, and the

No. of Experim't.	DATE.	Temp. of air outside enclosure at beginning of exp.	Temp. of air outside at the close of the experiment.	Temperature of air inside of the enclosing cylinder at the beginning.	Temperature of air inside at the end.	Evaporat'g point.	Temp. of water at the moment the iron was immers'd	Temperature of the water at end of the operation.	Temperature *gained* by the water.	Temperature lost by the iron.	Time elapsed during experiment.	Weight of water in grains Troy.
1	1835. Feb. 7,	65.5°	66.5°			50°	60.8°	68.1°	7.3°	143.9	91″	13022
2	"	68.25	69.5			50	59.9	67.3	7.4	144.7	109	13022
3	Mar. 21,	66.	66.	62.° 59.5	62° 59.9		51.74	59.87	8.13	152.13	376	12480
4	"	66.	66.	64. 62.9	64. 63.55		59.4	67.11	7.71	144.89		12480
5	"	67.	66.5	64.5 68.45	64. 68.3		57.15	64.96	7.81	147.04		12480
6	Mar. 28,	63.8	64.	63.7	63.9		60.	67.79	7.79	144.21	157	12480
7	"	65.	65.	64.	64.5		60.	67.78	7.78	144.22		12480
8	Apl. 25.	62.5	63.	60.5	60.5		54.51	62.52	8.02	149.48		12240
9	"	62.5	62.5	62.	63.		62.50	69.86	7.36	142.14		12240
10	"	63.	63.5	63.1	63.1		56.3	64.06	7.76	147.94		12240
11	"	63.	63.5	61.8	62.		56.3	63.90	7.60	148.1		12480
12	"	64.	64.	62.	62.2		56.3	63.91	7.61	148.09		12480
13	"	63.5	64.	61.9	62.2		56.3	64.10	7.80	147.9		12480
14	"	63.	63.	61.8	63.5		56.3	64.09	7.79	147.91		12480

TABLE IX.

cooling in sheet-iron cylinders of different thicknesses. The standard-piece at the time weighed 6000 *grains Troy, and its temperature at the commencement of every experiment was* 212°.

Weight of the iron containing vessel.	Equivalent of the thermometer in grs. of water.	Sum of the weight of water and thermometer equivalent.	Weight of water X its gain of temperature.	Weight of iron X its loss of temperature.	Weight of container X its gain of temperature.	Specific heat by formula. $\frac{T(w+e)}{it - Tg} = x.$	REMARKS.
1733	43.4	13065.4	95377.42	863400	12534.1	.112220	In this and the two following trials the container was exposed to the direct action of the air, and to radiation from the stove.
1733	43.4	13065.4	96683.9	868200	12705.8	.113010	Near the conclusion of this experiment the thermometer in the water rose rapidly, and soon after fell several tenths, indicating the existence of currents of unequally heated portions of water.
1733	196.	12676.	103055.8	912780	13959.21	.114655	The container was now placed on a charcoal stand within a tinned iron cylinder, 9 inches in diameter, 14 inches high, through the side of which, near the bottom, passed the stem of a thermometer, another being within it near the top, the scale projecting above.
1733	196.	12676.	97731.96	869340	13238.07	.114159	
1733	196.	12676.	98999.56	882240	13409.77	.113945	In this experiment, thermometers in the air were all observed to have fallen during the operation.
1733	196.	12676.	98746.04	865260	13375.43	.115914	A tin cover perforated at top to receive thermometers, and the iron to be tried, was now placed over the tin cylinder.
1733	196.	12676.	98609.08	865320	13358.26	.115743	Only one thermometer now placed in the inside of the tin vessel, its bulb at the level of the middle of the water cylinder.
5167	196.	12436.	99736.72	896880	41439.34	.116581	This experiment ended at the temperature of the air, and may be supposed to give a result too high; a little pressure of steam in the boiler.
5167	196.	12436.	91529.	852840	38029.12	.112321	This experiment having been begun at the temperature of the air may be supposed to give a result too low, the inner air-thermometer rose above the exterior air.
5167	196.	12436.	96495.6	887640	40095.92	.113735	
5167	196.	12676.	96339.	888600	39269.2	.113418	Half an ounce more water used in this than in the 3 preceding experiments. Care was taken to regulate the height of the furnace so as to keep the temperature precisely at the boiling point, and not to increase the pressure.
5167	196.	12676.	96456.75	888540	39320.87	.113713	
1733	196.	12676.	98875.8	887400	13517.6	.113142	These two experiments in the thinner cylinder were intended to furnish a means of comparing the 2 vessels with each other. The result shows the specific heat of sheet iron = .101714. With this specific heat, the mean result of the last four trials is .112945.
1733	196.	12676.	98738.25	887460	13500.07	.112962	
					Mean of 14=	.113963	

After the preliminary series already given, (Tab. IV.) two other sets of experiments were made, one in each of two glass vessels similar to that in which the preceeding trials had taken place,—equal to each other in liquid capacity, but of different thicknesses; the one being more than four times as heavy as the other. Table V. contains the experiments with the thicker, and table VI., those with the thinner of these vessels. The particular object of these trials was to determine, if possible, the effect of the containing vessel on the general result of the experiment; in other words, to decide its specific heat, by observing the difference which would arise from a mere change of thickness in the containing vessel, while all other circumstances of the trial were the same, in both cases. A comparison of several experiments in each table, with corresponding ones in the other, will show that when the water at the commencement was from 60° to 63.5°, the actual difference in the rise of temperature, due to a difference in the weight of the containing vessels of (12272—2996)=9276 grains of glass, was about three tenths of a degree; and from the comparison of nine experiments in the first of these tables, with the same number in the second, it will be seen that we obtain for the specific heat of glass .111063.* A part of the trials in these and the subsequent series were made by means of the spirit thermometer C, the equivalent of which was only approximately found, on account of not having taken the precaution to weigh the bulb and tube separately before filling the instrument. It is, also, like all other spirit thermometers, liable to some uncertainty in its indications owing to the different quantities of the liquid which may at different times be taken up in wetting the tube,—an uncertainty, which is the greater, the more sudden are the changes to which we submit the instrument.

The equivalent value assigned to it by finding the weight and capacity of an equal length of the same tube is 117.4 grains of water, as hereafter mentioned.

The next apparatus used in this part of the investigation consisted of two glass jars, smaller than those above described, both of the same capacity, but differing from each other in weight, being nearly in the proportion of 3 to 1. The experiments in these two vessels were made in two sets of 6 each, three of each set being commenced in the thicker vessels at a temperature of 60°, and three at 60.5°; and the same number at the same two points in the thinner. The results are contained in table VII., where it will be perceived that from five comparisons between the trials in these two jars the influence of the glass is such as to indicate a mean specific heat of .103086, which taken with the above result of the 9 comparisons

* The principle of calculation applied to all these comparisons is embraced in the formula $x=\frac{(T't-Tt').(w+e.)}{Tt'g-T'tg'}$, where x is the specific heat of the container; T' is the gain of temperature by the water when the thinner glass is used; T the gain when the thicker vessel is employed; t', is the loss of temperature by the iron when the thinner, and t, that when the thicker is employed; w, is the weight of water in both cases, and e the equivalent in grains of water, of the liquid in the thermometer; g is the weight of the thicker jar; g' that of the thinner. Thus comparing the two identical experiments 7 and 8, table V., with experiment 6, table VI. in which the initial temperature of the water, and other circumstances, coincided with the former, we have $T'=5°.76$; $t=143°.1$; $T=5°.4$; $t'=142°.74$; $w=$ 16494.5 grs.; $e=152.7$ grs.; $g=12.706$ grs., and $g'=34.30$ grs. Hence $T't$ $=824.256$; $Tt'=770.796$; $T't-Tt'=54.46$; $w+e=16.647.2$; $Tt'g=$ 9793733.976; $T'tg'=2827198.08$; from which $x=.130156$ the specific heat of the glass by this comparison.

between tables V. and VI., gives a mean specific heat of flint glass of .107074.

As we are now only referring to the *apparatus* employed, we shall reserve our remarks on the results presented by these tables, respecting the specific heat of *iron*, until we have described the other methods of verifying their correctness.

The fourth set of apparatus for this purpose, consisted of two cylindrical copper vessels, of the same height as the glass ones already described: but of such diameter as to contain about 38600 grains, or a little over $5\frac{1}{2}$ pounds avoirdupoise of water, and so differing in thickness, that the one weighed nearly 4 times as much as the other. The mode of conducting experiments in these two vessels, and the principle of calculation applicable to them, is entirely similar to that already given for the two pairs of glass jars,—except that the equivalent of the glass in the thermometer, was now separately computed.

The results will be found in table VIII., in which it will be perceived that the number of comparisons furnishing data for determining the specific heat of copper, is but two, and of these only one can be considered entirely unexceptionable.

From this it should seem that the specific heat of copper is .10431, whereas the four determinations of Wilke, Crawford, Dalton and Petit and Dulong give .10750 for the specific heat of that metal.

A fifth mode of determining the specific heat of iron was by employing as water vessels two cylindrical sheet iron jars of the same capacity, but of thicknesses differing from each other in about the proportion of 3 to 1. As in the preceding sets, the specific heat of the container may here be found by comparing together experiments made at the same temperature, in the two vessels; and this ought to give their variation, if any exist, from the specific heat of the standard piece itself. Another method is to assume that the specific heat of the standard piece and of the sheet iron containers is the same.* The use of the two containers in this latter case serves only to verify each others results, since each furnishes a separate and independent calculation.

The results of experiments in the two iron vessels will be found in table IX. A comparison furnished by two experiments in each vessel, gives by calculation on the principle used in the case of the glass containers the specific heat of the Russian sheet iron, of which they are composed$=$.101714.

Results of Experiments on Specific Heats.

When it is considered that numerous causes interfere with the operations on specific heats, it cannot be expected that one, or a few trials, should be deemed sufficient to settle so difficult and intricate a question. For this reason the committee preferred the method of multiplying and varying the trials, and making a deduction from the mean results, in order to verify the general efficacy of the standard piece, in producing vapour.

1. The first part of the *preliminary series* (table IV.) indicates the effect of radiation from surrounding objects in the apartment to the water

* The formula in this case gives the specific heat of iron $z=\dfrac{T(w+e)}{it-i'\,T}$ where T is the temperature gained by the water, $w=$ the weght of water in grains, $e=$ the equivalent of the thermometer in grains of water; $t=$ the temperature lost by the standard piece; $i=$ the weight of the standard piece in grains, and $i'=$ the weight of the sheet iron containg vessel. See *Am. Jour. of Sci.* Vol. 27, p. 277.

vessel. The 13 experiments constituting this part of the table, exhibit a mean result of .123004 as the specific heat of iron.

2. The second part of the same series in which the cylinder B. was employed, indicates a decided effect from that precaution, and gives as a mean result .11294, for the specific heat.

3. Experiments No. 16, 20, 23, 25 and 26, the greatest number of comparable results in this part of the series, (differing only in the fourth place of decimals,) gives a mean of .11346.

4. In table V., where the thicker of the two glass cylinders of the same capacity was used, we have the mean result of the whole 14 experiments .11288.

5. The four experiments No. 2, 5, 6, and 9, which are the greatest number that conform to the third place, give a mean result of .11349.

6. The 10 experiments in table VI., made in the thin cylinder of the same capacity as the foregoing, give the specific heat =.11308.

7. Experiments No. 2, 5, 6 and 7, the greatest number of those which may be regarded as conformable to the third place of decimals, give a mean of .11361.

8. Table VII. contains 3 experiments made in each of the two vessels used in that series, which were performed under a cone of tinned iron to defend the water vessel from radiated heat, but as it was set loosely on the table which supported the container, it did not prevent the motion of air around the latter, and as the experiments made in this manner terminated from three to four degrees above the temperature of the room, there is reason to suppose that the results of those 6 experiments are all below the truth. Taking then the other six of this table, which were made with the same precautions as those in table V. and VI., we have as the mean result in the thicker glass .112952 ; and that in the thinner .113631.

9. The two experiments which confoim entirely with each other, for the thicker vessel, give the specific heat .113498, and the two for the thinner .113489.

10. The mean of *all* the results, including both those obtained with the cone, and those with the cylinder of tinned iron, to defend the water vessel, give a mean result of .112350, and the six rejected experiments taken by themselves .111511.

11. In the thinner copper vessel, the trials as recorded in table VIII, exhibit the mean of seven results equal to .115752

12. Rejecting those which began and ended too low, and hence gained heat from the air, as well as from the iron, we have in the thinner vessel .112577 as the mean of four experiments which are considered comparable.

13. In the same table eleven experiments in the thicker vessel indicate a a mean of .114990.

14. With the same jar, seven experiments which are considered *comparable*, give a result equal to .113261.

15. In the thick sheet iron cylinder, weighing 5167 grains, we find by table IX., that the mean of five trials gave a result =.113953.

16. In the same vessel, three experiments which differ only in the 4th place of decimals give a mean specific heat =.113622.

17. In the thinner sheet iron jar weighing 1733 grains, nine trials gave a mean result of .112972.

18. Three experiments in this vessel which differ only in the fourth place of decimals, give a mean of .113365.

The following table embraces a synoptical view of the experiments on specific heat thus far detailed.

TABLE X.

No. of the comparison.	No. of the table referred to.	Kind of containing vessel used.	Weight of the vessel in grs.	No. of experiments compared for the general mean.	Mean of specific heats from a comparison of all the trials.	No. of comparable experiments differing in the fourth place of decimals.	Mean specific heat by the comparable results.	No. of rejected experiments.	Mean specific heat by the rejected experiments.
1	IV.	Thin glass.	3325.	13	.112940	5	.113460	13	.123004
2	V.	Thick glass.	12272.	14	.112880	4	.113490		
3	VI.	Thin, containing same as preceding.	2996.	10	.113080	4	.113610		
4	VII.	Thick small glass.	6923.	3	.112952	2	.113498	6	.111511
5	VII.	Thin small glass.	2465.	3	.112931	2	.113489		
6	VIII.	Thick copper.	19738.	11	.114990	7	.113261		
7	VIII.	Thin copper.	5178.	7	.115752	4	.112577		
8	IX.	Thick iron.	5167.	5	.113953	3	.113622		
9	IX.	Thin iron.	1733.	9	.113972	3	.113365		
				75	.113716	34	.113374	19	.117257

Hence it appears that by a mean of 34 out of seventy-five experiments in nine different vessels, with five different liquid capacities, and composed of three different kinds of materials, we obtain a result not sensibly varying from .1134, as the specific heat of the iron standard piece between ordinary temperatures and 212° Fahrenheit.

The next step in this investigation again required the use of the copper cylinders, but instead of the *heating apparatus* W being filled with water, it was made to contain mercury, which allowed a higher temperature to be given to the vessel M. This latter vessel was now filled with melted tin, instead of mercury, as well to avoid the inconvenience from mercurial fumes, as to obtain the specific heat of iron at a second fixed temperature, the melting point of tin. It needs scarcely be mentioned, that the same degree of exactness in the accordance of experiments at temperatures above 400°, as at 212°, is hardly to be expected. Table XI. exhibits a number of trials made in the manner just pointed out.* A certain amount of error may possibly have been introduced into these experiments by the want of uniformity throughout the mass of melted tin; for, after withdrawing the standard piece and lowering the thermometer to the bottom of M, it was found that a difference of a few degrees, was a possible occurrence; but as the bulb of the mercurial thermometer, which marked the temperature of the melted tin, was generally kept at the same level with the centre of the standard piece, any difference between the two, must be trifling in amount.

* It will be evident on a comparison of this table with those which have preceded, that the general law observed by Petit and Dulong [*Ann. de Chim. et de Phys.* Vol. VII.] of an increase of specific heat by increase of temperature, when the method of heating water is employed, is confirmed by these results; but experiments on the production of vapour hereafter given, exhibit a very striking conformity, in regard to specific heat, with those made below 212°.

TABLE XI.

Experiments to determine the specific heat of the standard piece of the steam pyrometer at temperatures above 212°—*containers, two copper cylinders, weight of standard piece* 6000 *grains. Heating performed in bath of mercury or melted tin.*

No. of the experiments.	Temp. of air outside of tin cylind. at beginning.	Temperature of air *outside* at end.	Temp. *inside* of cylinder at beginning.	Temperature of air *inside* at the end.	Temperature of water at the beginning.	Temperature of water at the end.	Temperature of iron at immersion.	Temperature lost by the iron.	Temperature gained by the water.	Weight of water in the container.	Weight of copper in the container.	Equivalent of container in weight of water.	Equivalent of thermometer in water.	Total matter heated.	Specific heat.	REMARKS.
	°	°	°	°	°	°	°	°	°	grs.	grs.	grs.	grs.	grs.		
1	71.5	71.	67.6	67.4	61.4	67.45	400	332.55	6.05	38659	19718	2050	196.7	40905.7	.12403	The equivalent of the container is found by multiplying its weight by the specific heat of copper already ascertained. Ending at the temperature of the internal air; this result must be too high.
2	70.	71.	66.8	68.1	63.45	73.40	610	536.6	9.95	38659	19718	2050	196.7	40905.7	.12641	Began 3.35° below, and ended 6.6° above the air inside the shield. Air gained 1.3°.
3	71.	71.	67.7	67.7	58.75	68.3	560	491.7	9.55	38659	19718	2050	196.7	40905.7	.13241	Water at beginning 8.95° below air in shield; at the end, .6° above it.
4	80.	80.	75.	78.	71.8	78.55	442	363.45	6.75	38659	19718	2050	100.	40809.	.12631	Water at beginning 3.2° below internal air, at the end 3.55° above it; air *inside* gained .1° during the operation—*outside* air above temperature of water for the whole time, result must be too high.
5	80.	80.	75.1	75.25	67.9	74.75	442	367.25	6.85	38659	5168	531	100.	39290.	.12214	Water at beginning 7.2° below air inside, and .5° at end, leading to too high a result.
6	80.5	85.5	79.5	81.	71.9	78.7	446	367.3	6.80	38659	5168	531	43.7	39233.7	.12110	Water at beginning 7.6° below the internal air, and .8° at the end, result as before—inside air gained 1.5°.
7	85.	86.	80.	81.5	76.	83.26	450	366.74	7.26	38659	5168	531	43.7	39233.7	.12944	Began .4° below internal air—ended 3.26° above it, air inside gained 1.5° during the experiment.

The last arrangement for demonstrating the specific heat of iron, was in the nature of a verification of the methods already detailed, by means of a direct application of the standard piece to the purpose for which it is ordinarily employed—that of generating vapour instead of heating water.

It was, for this purpose, heated as before described, in the bath of melted tin to such temperatures, above 212°, as were deemed necessary, and immediately plunged into boiling water. The *effect* produced, was now ascertained by multiplying together the weight of vapour generated, and the latent heat of steam; while the *cause* was found in the weight of iron, its specific heat and the temperature which it expended. The shield to defend the iron in transitu was employed, and the other precautions to avoid error were still persevered in. The results will be found in table XIII.

Before proceeding however with the detail of those trials, it is necessary to state the mode of ascertaining the latent heat of the vapour of water, which enters as an essential element into the calculations of that table. It will be perceived that the principle of the method is similar to that of Count Rumford.

Apparatus for the latent heat of vapour.

The apparatus by which the latent heat of vapour was examined, is represented in plate 8, in which A is a cylindrical vessel to contain water; B a larger cylinder formed of pasteboard, higher than the preceding, surrounding and defending it from the air; C is a stand of charcoal on which the vessel rests; D is a vessel of tinned iron 14 inches high by 9 in diameter, to prevent the vessel F (the same which has already been described as the boiler of the steam pyrometer,) from affecting by radiation the temperature of A. P is a sheet of tinned iron, attached in a vertical position to the edge of the table T, serving still further to defend A from the influence of radiation from the boiler or steam pipe. S is a cylindrical piece of cast iron, having round its lower base a ridge *r*, adapted to retain a hold of the small hook *h*, within the copper case L, intended to receive it when hot. From the upper conical part of this case rises a pipe *g*, $\frac{1}{4}$ of an inch in diameter, curved into a semi-circle at the top to dip under water. Within the curved part is a stop-cock K, adapted to regulate, or entirely to prevent when required, the flow of steam from L. At *q* is an enlargement of the pipe *g*, with a funnel-shaped tube to receive the bulb of a thermometer *e*, sustained and made tight by packing around the lower part of its stem. The purpose of this thermometer is to mark the temperature of the effluent steam. *w* is a handle formed by a number of folds of flannel made fast to the pipe. *x* is a thick roll of cloth surrounding *g* and preventing the escape of vapour exterior to the tube. The thermometer *o* marked the temperature of the apartment in the immediate vicinity of the apparatus. *i* gave that within the pasteboard case, while *t* gave the temperature of the water in A.

No fire was kept in the apartment where the experiments were performed. The container A, when quite dry, was first accurately counterpoised in a scale pan, and then taken out and weights substituted to avoid any possible error in the scale beam. The vessel being next returned to the scale pan instead of the weights, was filled so nearly with water, that the vapour to be condensed, would make it quite full; after which a counterpoise was once more effected, and the vessel being taken to its place within B, the weighing by substitution was repeated, giving the sum of the weights of the water and of its container. The counterpoise being once adjusted for a series of experiments, it was only necessary in repeating the trials with new portions of water to replace the vessel A in the scale pans, and

pour in a fresh charge of water till the equilibrium was obtained. The several thermometers were next adjusted in place, that which was to indicate the temperature of the water being made with special reference to these trials, and the weight of mercury which it contained, as well as that of the glass immersed in the water exactly ascertained.

While the operations of weighing and arranging, as just described, were performed by one assistant, another having heated to a low red heat the cylinder S, inserted it in the copper case L, where being retained by the hook h, it was plunged into the boiling water contained in F, and the latter placed within D; the packing x was adjusted, and stop-cock K opened, to allow the air to be driven from the pipe g, and the whole apparatus, including the thermometer e, to be raised to the temperature of 212°. This being done, the apparatus was conveyed to the room where the water vessel was placed, and after turning the stop-cock for an instant, to expel any water which might have been condensed during the transit, the mouth of the pipe was brought briskly round and immediately plunged under the water. Here it was continued until the vessel A was perceived to be full, when it was withdrawn and the stop-cock closed, but not until the mouth was quite above the water. During this manipulation the thermometer t was kept constantly moving, to equalize the temperature of the water. This being done, the increase of weight was ascertained by again counterpoising the vessel and its contents. It is apparent that heat imparted to the water, by the condensed vapour, must be employed for heating at least three different bodies, the water, the container and the thermometer t.

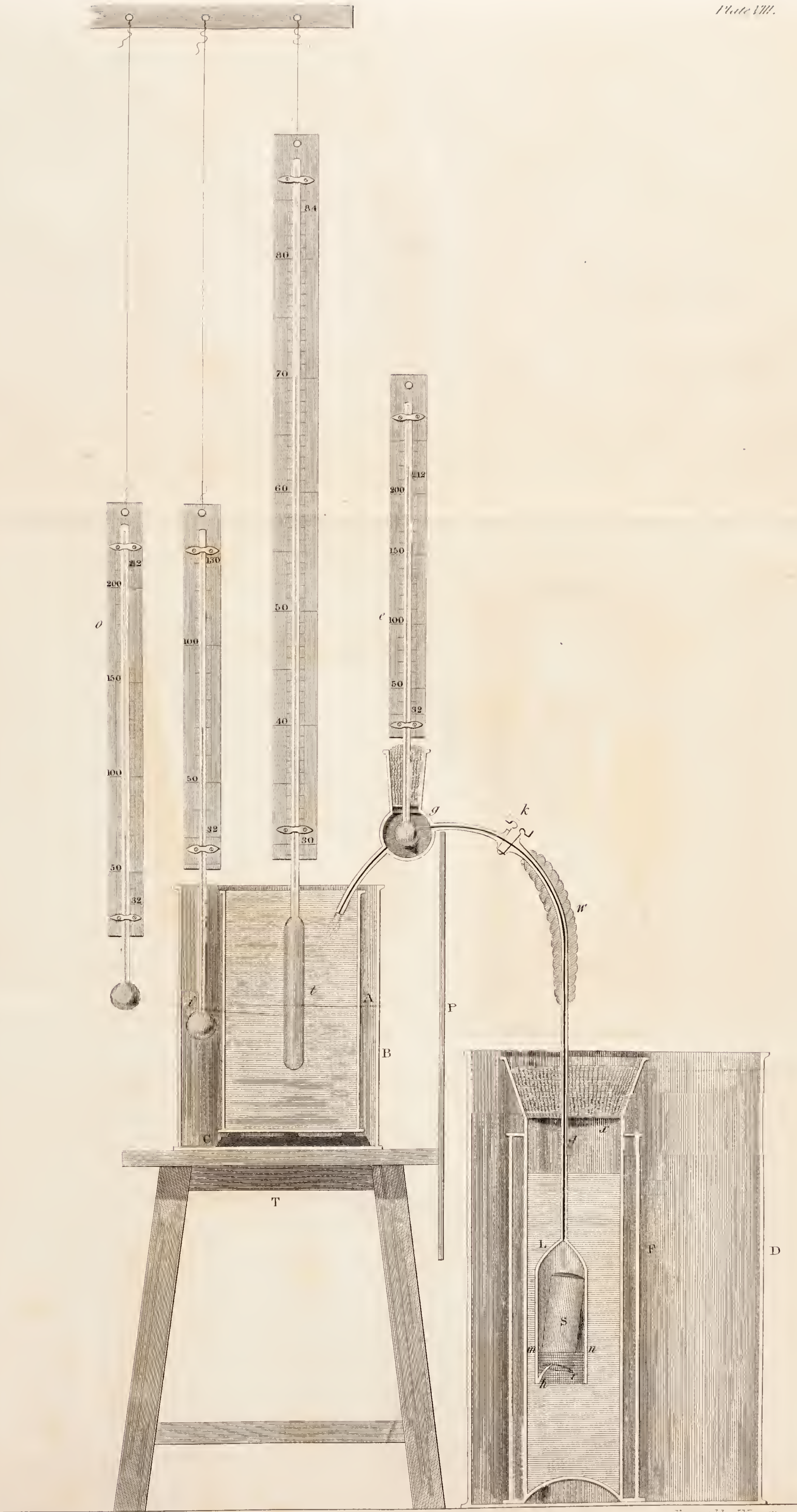
It was therefore necessary to know the weight and specific heat of each, in order to determine the relation of the heating power of a given weight of steam, compared with the cooling power of a quantity of water equivalent to the sum of these three bodies. As the quantity of air which was included in the box B was small in amount, as the specific heat of air is, weight for weight, but about one fourth that of water, and as the experiments were generally performed in such a manner as to allow the air to operate partly in favour, and partly against the heating power of the steam, it was not deemed important to take into the calculation the minute quantity due to the cooling power of this mass of air. In a few instances however, its effects are noted in the column of remarks.

The results of experiments on this subject are found in table XII.

As the trials on specific heats below 212° had preceded those now under consideration, it was found convenient, to employ as containers some of the same cylindrical vessels which had been used in that investigation. The materials of each are specified in the table. The calculations are very simple when we have obtained an expression for the equivalent quantity of water equal to the three terms above specified.*

* The latent heat of steam was calculated by the following formula.

Putting $w =$ the weight of water in the vessel.
$n =$ that of the vessel itself.
$g =$ that of the glass in the immersed part of the thermometer.
$m =$ that of the liquid in the same.
$x =$ the specific heat of container.
$y =$ do. of glass.
$z =$ do. of the thermometric liquid.
$v =$ the weight of vapour condensed.
$T =$ the temperature gained by the water.
$t =$ the distance of the final temperature of the water below that at which the steam enters it,
and $l =$ the latent heat of vapour at the boiling point.



Wm. Mason Del.

Engraved by J. Yeager.

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Results of Experiments on Latent Heat.

The accompanying table presents the determination, in the manner already described, of the latent heat of the vapour of water. The trials were made in four different cylindrical vessels, one of copper, two of glass, and one of sheet iron.

The quantities of water varied from about 13000 to upwards of 39000 grains.

The equivalents of the thermometers were either approximately estimated by knowing the size and thickness of the bulbs, or were actually determined by weighing before and after filling, and in every instance the calculation for the thermometrical equivalent, was made only on the part of the instrument actually immersed.

It will be perceived that three out of the four vessels, give mean results which differ from each other by not more than 3 degrees. The third set, or that made in thin glass, and which differs widely from all the rest, ought probably to be rejected. If this be done, the other three sets give a mean result equal to 1037 degrees; which is 3.8 degrees less than that obtained by Count Rumford. Including the third set, the mean result will be 1026.83. As the steam rising up in the case L, necessarily came in contact with the hot iron S, it became, to a certain extent, surcharged with heat; but as the thermometer indicated its temperature at the moment of escape, an allowance is easily made for the surcharge. The rapidity of flow being duly regulated by the stop-cock k, the steam was prevented from carrying over any water in an unvaporized state. As the amount of surcharge seldom exceeded 3 degrees, it was not considered necessary to calculate for the difference between the specific heat of vapour and that of water. By the experiments of Delaroche and Bérard, the specific heat of vapour, compared with that of water, is .847 to 1.000. Admitting this to be true, the result must, in any case which has occurred to the committee, be but little affected by allowing for the difference.*

Then the heating effect is represented by $T \times (w + nx + gy + mz)$, and the cooling effect by $v \times (l + t)$; whence $v \times (l + t) = T \times (w + nx + gy + mz)$ and consequently $l = \frac{T(w + nx + gy + mz)}{v} - t$.

* The experiments hitherto published, had left some doubt as to the true latent heat of vapour. Black first obtained the number 810°; Watt afterwards gave it 950°; Southern produced 945; Lavoisier made it rather more than 1000°; Rumford 1040.8; Despretz 955.8; Ure 1000; Thompson "more than 1000°." Watt and Clement have both established the position that the latent heat of steam, added to the sensible heat above 32°, is nearly a constant quantity. As, however, the point 32° is entirely arbitrary, and as no temperature is now *known*, at which vapour does not rise from water or ice, there is reason to suppose that in strictness, the constant—if there be one—is different from that which these experimenters have derived. If not, the latent heat of vapour must diminish below 32° as the temperature diminishes.

TABLE XII.

Experiments to determine the latent heat of Steam, employing a given weight of water in a vessel of known weight and specific

No. of Experim't.	DATE.	Kind of vessel which contained the water.	Temp. of air outside at beginning.	Air outside at the end.	Air inside of the box at beginning.	Air inside at the end.	Temp. of the water at beginning.	Temp. of water at the end.	Gain of temp. by the water.	Weight of vapour condensed.	Weight of water in the container.	Equivalent of the thermometer.	Weight of the container.
			°	°	°	°	°	°	°	grs.	grs.	grs.	grs.
1	1835. Aug. 18,	thin copper	84.	85.			75.35	86.1	10.75	347	38659	100	5178
2	"	"	83.	83.			70.9	85.75	14.85	504	38659	100	5178
3	"	"			72.25	72.6	68.75	75.75	7.	241	39305	30	5178
4	"	"			72.60	73.	70.	77.25	7.25	250	39305	30	5178
5	"	thick glass	80.45	80.67	78.5	82.	74.6	92.65	18.05	299	17112	43	12272
6	"	"	80.85	81.	81.	82.	75.5	88.	12.5	192	17112	43	12272
7	Sep. 19,	"	67.5	67.55	68.	68.	64.6	74.5	9.9	156	17428	7.3	12272
8	"	"	67.7	67.7	68.	68.	65.25	73.25	8.	127	17428	7.3	12272
9	Sep. 12,	thin glass			73.4	73.6	68.5	78.5	10.	167	18405	30	2986
10	Sep. 26,	"	60.4	60.7	60.5	61.	58.5	68.5	10.	156	17428	7.3	2986
11	Sep. 5,	thick sheet iron	81.1	81.15	81.5	82.	75.1	89.2	14.1	169	13152	43	5167
12	"	"	81.4	82.6	81.	82.	73.7	89.8	16.1	190	13152	43	5167

TABLE XII.

heat, to receive and condense the vapour as it passed from the mouth of the pipe.

Equivalent of the container.	Total equiv. of matter heated, estimated in grains of water.	Weight of water X gain of temperature.	$\frac{W \times T}{w}$	Temp. of steam on enter'g water.	Sensible heat lost by the steam.	Latent heat by separate experiments.	Latent heat by a comparison of different sets.	REMARKS.
grs.	grs.		°	°	°	°	°	
540.	39199.	421389.	1214.	214	127.5	1086.5		The equiv. of the therm. which marked the temp. in first 2 expts. is only estimated approximately. This expt. was made without the use of a 2d cylind. to defend the water vessel, and as it ended but little above the temp. of the air, the result must be somewhat too high.
540.	39199.	582005.	1154.7	215	129.25	1025.5		
540.	39875.	279125.	1158.2	215	139.25	1018.95		The time required to bring the water to a perfect state of uniformity in temp. after the steam was cut off, and the excess of its final temp. above that of the air, caused a slight error in defect. The container was surrounded by a pasteboard box.
540.	39875.	289094.	1156.3	214	136.75	1019.55	1037.87	
1342.5	18507.5	334060.4	1117.25	213	120.35	996.9		This expt. terminating more than 10° above the air, is evidently to be rejected for defect. The rise of temp. in the box proves this to be the case.
1342.5	18507.5	231343.	1204.82	215	127.	1077.82		The pipe was withdrawn from the water before closing the stop-cock, in order to prevent the rushing up of water.
1227.	18662.3	184756.7	1184.3	214	139.5	1044.8		Do. Therm. very small, but with along stem to extend nearly to the bottom, formed of 59 grains of glass, & containing 42 1-2 grs. of mercury.
1227.	18662.3	149298.4	1175.5	213	139.75	1035.75	1038.51	Do.
299.	18734.	187340.	1121.8	213	134.5	987.3		The bulb of the therm. estimated approximately.
299.	17734.3	177343.	1146.8	212	143.5	1003.3	995.3	This expt. terminated 8° *above* the initial temp. of the air in the box, and began only 2° below it, consequently lost some heat, & gives a result rather too low.
586.	13781.	194312.1	1150.	213	123.8	1027.2		
586.	13781.	221874.1	1167.7	214	124.2	1043.5	1035.35	

Specific Heat by Vaporization.

Having determined the latent heat of vapour, it is not difficult to verify our preceding determinations of the specific heat, by operating in precisely the same manner as we do to obtain the temperature of a body,—except, that the temperature of the bath of melted metal is now first ascertained by the mercurial thermometer; and the actual temperature of the standard piece being then known, is compared with the weight of vapour which it produces, by cooling in boiling water from its initial temperature down to 212°. These experiments were made both before and after the screw beam and counterpoise were changed. The weight of the standard piece is, in both cases, taken in degrees of the pyrometer scale as existing at the time.

It will be seen, that, assuming as correct the determination of latent heat, made by the committee (1037°), the experiments given in the accompanying table (No. XIII.) afford results for the specific heat of iron as follows:—

1. Taking the mean of 29 experiments, it is . . .	.11325
2. Taking only those made before the screw beam was changed, (9 experiments,) we obtain . . .	.11340
3. Taking together the last 20 experiments of the table, we have	.11324
4. Experiments Nos. 7 and 8 with the first screw and counterpoise, differing only in the 5th place of decimals, give	.11336
5. Six out of the last 20, differing only in the fourth place, give	.11356
6. The mean result of these 5 comparisons, is . .	.11336

As a mean of the nine sets of experiments in different vessels, the specific heat below 212°, determined by heating water, as above detailed, was found=.113374. As the calculations just detailed are carried only to the 5th place, the two results may be considered as differing from each other only by $\frac{1}{11337}$th part of the total value.

Of those experiments which differ considerably from the general result, about the same number was found above, as below the *mean*, showing that if these discrepancies be due to errors of observation, they are, as we ought to expect, liable to be either in excess or defect; and that they counterbalance each other.

The eight experiments, of which the results differ only in the 4th place of decimals, were made at temperatures varying from 392 to 595, without indicating any decided difference in the specific heat of the metal within those limits.

Of the extreme results in the table, the highest was obtained at 480° and the lowest at 488°;—the next to the highest, at 500°, and the next to the lowest, at 292°.

From the exact conformity of the general results of the method of evaporation, and that of heating water, in trials below 212°, it appears that if the specific heat of the standard piece be determined by the latter method, and its weight be duly regulated to conform to the length of the threads of the screw beam,—and to the weight of the revolving counterpoise, its indications of temperature will be such as to connect themselves immediately with those of the mercurial thermometer.

TABLE XIII.

Experiments to determine the specific heat of the standard-piece of wrought iron used in experiments with the Steam Pyrometer during this investigation. The heating performed in a bath of mercury or melted tin, and the effect measured by the weight of vapour carried off in cooling, from the first observed temperature down to 212°.

No. of the Experiment.	DATE,	Observed temperature of the iron.	Weight of steam which escaped.	Temp. lost by the iron in the generation of steam.	Weight of the standard-piece in pyrometric units or degrees.	Weight of iron X loss of temperature.	Weight of steam X latent heat (=1037°.)	Specific heat of iron from the preceding data.	REMARKS,
	1833.	°		°					
1	July 20,	600	390	388	9065.7	3517491	404430	.11494	In the first nine experiments the heating of the standard-piece took place in the heating apparatus used in trials on the metals, and the shield to defend it in passing to the boiler was not employed.
2	"	584	366	372	9065.7	3372440	379542	.11253	
3	July 27,	562	351	350	9051.4	3167990	363987	.11478	
4	"	556	334	344	9051.4	3113881	346358	.11123	
5	"	510	280	298	9051.4	2697317	323544	.11995	
6	"	576	351	364	9051.4	3294709	363989	.11047	
7	"	590	374	378	9051.4	3421429	387838	.11335	
8	"	595	379	383	9051.4	3466686	393023	.11337	
9	"	462	240	250	9051.4	2262850	248880	.10998	
	1835.								
10	June 5,	450	278	238	10443	2485434	285500	.11487	In this experiment the thermometer attached to the boiler had fallen 2 or 3° before the condenser was put on. In this and the eleven following experiments the heating was performed in a bath of mercury.
11	"	466	280	254	10443	2652522	290360	.10946	
12	"	454	273	242	10443	2527206	283101	.11589	
13	"	470	295	258	10443	2694294	305915	.11350	
14	"	480	333	268	10443	2798724	345321	.12338	The condenser kept off till the thermometer had fallen a little.
15	"	488	325	276	10443	2882268	337025	.11693	Condenser put on sooner than in the preceding case.
16	June 13,	476	302	264	10443	2756952	313174	.11359	
17	"	435	260	223	10443	2485434	269620	.10848	
18	"	462	287	250	10443	2610750	297619	.11399	
19	"	444	262	232	10443	2422776	271694	.11200	
20	"	392	205	180	10443	1879740	212588	.11307	
21	"	292	83	80	10443	815440	86071	.10555	
22	June 20,	535	370	323	10443	3373089	383690	.11374	In this and the following experiments a bath of tin was employed to heat the standard-piece.
23	"	490	307	278	10443	2903154	318353	.10965	
24	"	500	350	288	10443	3007584	362950	.12067	
25	"	492	320	280	10443	2924040	331840	.11348	
26	"	492	310	280	10443	2924040	321470	.10994	
27	"	492	330	280	10443	2924040	342210	.11703	
28	"	492	325	280	10443	2924040	337025	.11526	
29	"	488	290	276	10443	2882268	300730	.10433	
	Mean of 29 Experiments							.11325	

Heating and cooling of liquids.

In determining the specific heat of the iron standard-piece, it became evident that the influence of the air and other extraneous objects upon the temperature of the vessel of water could not be omitted, at least while the experiments were conducted, without enclosing the container in some other vessel which might shield it from the radiating and conducting power of surrounding bodies.

But in order to neutralize, as far as practicable, the disturbing influence of the causes just mentioned, it was evident that with a given state of the air and of other bodies, the water-vessel must be made to receive during an experiment as much heat from surrounding objects as it imparted to them. This could be effected only by commencing each experiment, so much below the temperature of the air, that, during the cooling of the iron in water, the temperature of the latter should, in rising, pass through the temperature of the air, and not only rise above it, but so divide the duration of the experiment that the cooling effect of the air in the latter portion of time should precisely equal its heating influence in the former.

It, therefore, became necessary to discriminate between the respective influences of hot iron and of the air, in order that the temperature of the water might be adjusted to that of the apartment before commencing the experiment.

By an examination of table XIV. it will be perceived that in twenty-three different experiments the times of rising through different stages of temperature are given, together with the initial and final temperatures of the air and of the water. It will not fail to be observed, that in comparisons of this nature, the materials and construction of the thermometer are elements of quite as much importance as the quantity of liquid heated, or the materials and other circumstances of the container.

Thus, it will be seen, that by a mean of 8 sets of observations in which the mercurial thermometer A (calculated to be equivalent to $152.7 + 43.45$) $= 196.15$ grains of water, was employed, the time required to obtain the full effect of 6000 grains of iron heated to 212°, and cooled in water at 60 or 64 degrees, was 148 seconds.

The quantity of water was varied from 12000 to 18000 grains.

With the mercurial thermometer B, estimated at about 43 grains of water, the time by 7 sets of observations was found to be 126 seconds; the quantity of water from 13000 to 20000 grains, and the vessel either of glass or sheet iron; the two latter circumstances serving to produce comparatively little effect on the time required to bring the temperature to a stationary condition.

With the spirit thermometer C, 8 sets of observations gave a mean duration of 295 seconds, the weights of water varying from 13000 to 18000 grs., and the container being either iron, weighing 1733 grains, or glass weighing from 2,900 to upwards of 12,200 grains. This last thermometer has a bulb $6\frac{1}{10}$ inches in length, and .5 inch in diameter, weighing 264 grains; and contained about 142 grains of alcohol, which, by the mean of 8 different determinations,* has a specific heat of .641, and consequently is equivalent to 91 grains of water, and the glass to 26.4 grains, whence the whole portion immersed was equivalent to 117.4 grains of water.

*See Thompson on heat p. 76.

TABLE XIV.

Synopsis of twenty-three sets of observations in six different series on the rate of heating in given quantities of water, by the cooling of the iron standard-piece weighing 6000 *grains.*

1st Series in thin glass jar weighing 3325 grains.—Water 20432.

No. of expt. & place in specif. heat series.	Temp. of air near the water vessel.	Temp. of wat. at beg. and end of observat'n.	Rise of temperature in wat.	Time elapsed during the rise.
1	61.9	54.5°	.5°	24″
Tab. IV. Exp. 22.		Ther.	1.	8
		B.	1.	13
		Mer-	2.	30
		curial.	.6	44
Result.	61.9	59.6°	5.1	119
2	63.5	60.	2.	17
Tab. IV. Ex. 23.		Ther.	1.	15
		B.	1.	12
			.4	30
			.1	8
			.1	7
			.1	5
			.1	10
			.1	45
Result.	63.5	64.9	4.9	149
3	63.5	64.9	1.1	19
Tab. IV. Ex. 24.		Ther.	1.	4
		B.	1.	7
			1.	12
			.3	19
			.1	11
			.1	22
Result.	63.5	69.5	4.6	94
4	71.	67.1	.9	19
Tab. IV. Ex. 25.		Ther.	1.	8
		B.	1.	8
			.5	8
			.3	7
			.2	6
			.2	15
			.2	9
			.2	17
			.15	30
			.05	18
Result.	73.	71.8	4.7	145
5	71.	67.1	.9	15
Tab. IV. Ex. 26.		Ther.	1.	8
		B.	1.	14
			1.	18
			.2	14
			.3	19
			.2	29
			.05	14
			.05	22
Result.	72.5	71.8	4.7	153

2d Series in an iron jar weighing 1733 grains. Water 13065.

No. of expt. & place in specif. heat series.	Temp. of air near the water vessel.	Temp. of wat. at beg. and end of observat'n.	Rise of temperature in wat.	Time elapsed during the rise.
1	65.5°	60.8°	1.2°	16″
Tab. VIII. Ex. 1.			1.	6
		Ther.	1.	3
		B.	1.	3
		Mer.	1.	3
			1.	4
			1.	5
			.4	4
			.1	5
			.1	6
			.2	11
			.1	17
			.1	15
			.1	19
Result,	66.	69.1	8.3	117
2	68.25	59.9	2.1	21
Tab. VIII. Ex. 2.		Ther.	2.	11
		B.	1.	8
			1.	13
			.4	7
			.4	9
			.2	10
			.1	9
			.1	11
			.1	10
Result,	69.5	67.3	7.4	109
Tab. VIII. Ex. 3.	52.5	50.6	.4	20
		Ther.	1.	10
		C.	1.	16
		Spirit.	1.	12
			.4	7
		{Water 12487 gr's}	.2	5
			.2	4
			.2	4
			.2	2
			.2	13
			.2	2
			.2	4
			.2	7
			.2	5
			.2	6
			.2	9
			.2	8
			.1	13
			.1	5
			.1	12
			.1	11
			.1	17
			.1	28
			.08	31
Result,	52.5	57.58	6.98	251

Remark.—The observations in this table were taken during the several series of experiments on specific heats—the temperature of the iron at each trial being 212 degrees.

TABLE XIV.—*Continued.*

3d series in a glass jar weighing 2996 grains.—Water 16947.

No. of expt. & place in specif. heat series.	Temp. of air near the water vessel.	Temp. of wat. at beg. and end of observat'n.	Rise of temperature in wat.	Time elapsed during the rise.
1 Table VI. Expt. 1.	57.5°	56.90°	.91°	25″
		Ther.	1.	15
		C.	1.	20
		Spirit.	.5	10
			.5	12
			.5	14
			.2	7
			.2	7
			.2	9
			.1	1
			.1	8
			.1	7
			.1	5
			.1	8
			.1	6
			.1	7
			.15	24
Result.	58.	61·95	5.86	185
2 Tab. VI. Exp. 2.	58.5	52.62	.38	13
		Ther.	1.	14
		C.	.5	10
			.5	9
			.5	11
			.5	12
			.5	11
			.2	4
			.2	7
			.2	8
			.1	2
			.1	5
			.1	6
			.1	6
			.1	5
			.1	7
			.1	5
			.1	8
			.1	11
			.1	10
			.1	13
			.1	18
			.1	25
			.1	46
			.2	59
Result.	59.	58.7	6.08	325
3 Tab. VI. Ex. 3.	57.	52.33	.67	19
		Ther.	1.	14
		C.	1.	16
			.5	10
			.5	15
			.5	13
Carried up.			4.17	87

No. of expt. & place in specif. heat series.	Temp. of air near the water vessel.	Temp. of wat. at beg. and end of observat'n.	Rise of temperature in wat.	Time elapsed during the rise.
Brought forward.			4.17°	87″
Tab. VI. Ex. 2.			.5	15
			.2	11
			.2	13
			.1	9
			.1	9
			.1	11
			.1	15
			.1	19
			.1	34
			.11	26
Result,	57.5	58.11	5.78	249
4. Tab. VI. Ex. 4.	56.5	49.35	.65	15
		Ther.	1.	13
		C.	1.	14
			1.	18
			1.	22
			1.	27
			.1	10
			.1	11
			.1	13
			.1	22
			.1	31
			.1	63
			.06	205
Result,	56.5	55.66	6.31	464
5. Tab. VI. Ex. 5.	67.2	63.51	.49	16
		Ther.	1.	7
		A.	1.	7
		Mer.	1.	10
			1.	13
			.5	11
			.5	28
			.1	18
			.1	33
			.02	11
Result,	67.5	69.22	5.71	154
6. Tab. VI. Ex. 6.	67.1	63.5	.5	15
		Ther.	1.	8
		A.	1.	7
			1.	9
			1.	15
			.5	14
			.5	27
			.1	13
			.1	19
			.06	30
Result,	68.2	69.26	5.76	157

TABLE XIV.—*Continued.*

4th series in glass jar weighing 12272 grains.—Expts. 1, 2, 3, 4, water 18158. Experiment 5, water 17902.

No. of expt. & place in specif. heat series.	Temp. of air near the water vessel.	Temp. of wat. at beg. and end of observat'n.	Rise of temperature in wat.	Time elapsed during the rise.
1	58.75°	52.62°	.38°	16″
Tab. V. Ex. 1.		Ther.	1.	10
		C.	1.	17
		Spirit.	.5	11
			.5	13
			.5	12
			.5	16
			.2	9
			.2	12
			.1	8
			.1	7
			.1	9
			.1	12
			.1	16
			.1	29
			.1	77
			.005	39
Result,	58.5	58.105	5.485	313
2	57.	56.09	.91	26
Tab. V. Ex. 2.		Ther.	1.	13
		C.	1.	18
			.5	14
			.5	13
			.5	15
			.5	28
			.1	12
			.1	7
			.1	9
			.1	11
			.1	15
			.1	23
			·05	10
			.05	39
			.01	37
Result,	58.25	61.71	5.62	290
3	57.75°	52.33°	.67°	21″
Tab. V. Ex. 3.		Ther.	1.	14
		C.	1.	19
			1.	26
			.5	15
			.5	20
			.3	20
			.1	9
			.1	13
			.1	15
			.1	21
			.05	23
			.05	24
			.03	79
Result,	uncer.	57.83	5.50	319
4	67.1	63.5	1.5	24
Tab. V. Ex. 5.		Ther.	1.	5
		A.	1.	9
		Mer.	1.	17
			.7	25
			.1	12
			.1	20
			.04	23
Result,	68.5	68.94	5.44	135
5	67.1	63.52	.48	18
Tab. V. Ex. 6.		Ther.	1.	6
		A.	1.	6
			1.	9
			1.	14
			.4	12
			.1	4
			.1	5
			.1	5
			.1	10
			.1	18
			.05	27
			.02	23
Result,	67.7	68.97	5.45	157

TABLE XIV.—*Continued.*

5th series in a glass jar weighing 6923 grains.—Water 11764.									
No. of expt. & place in specif. heat series.	Temp. of air near the water vessel.	Temp. of wat. at beg. and end of observat'n.	Rise of temperature in wat.	Time elapsed during the rise.	No. of expt. & place in specif. heat series.	Temp. of air near the water vessel.	Temp. of wat. at beg. and end of observat'n.	Rise of temperature in wat.	Time elapsed during the rise.
1 Tab. VII. Ex. 4.	65.2°	60.°	1.°	10″	3 Tab. VII. Ex. 6.	65.°	60.01°	.99°	12″
		Ther.	1.	5			Ther.	3.	15
		A.	1.	5			A.	1.	6
		Mer.	1.	6				1.	7
			1.	6				1.	9
			1.	7				.5	8
			1.	11				.5	12
			.5	9				.1	5
			.5	17				.1	6
			.2	13				.15	10
			.1	14				.08	35
			.06	34					
					Result,	65.3	68.38	8.37	125
					6th series in a thin glass jar, weighing 2469 grains—water 12243.				
					1 Tab. VII. Ex. 10.	66.1	60.	1.	11
Result,	65.7	68.36	8.36	137″			Ther.	1.	6
							.A	1.	6
2 Tab. VIII. Ex. 5.	65.9	60.02	.98	10				1.	7
		Ther.	1.	5				1.	8
		A.	1.	5				1.	12
			1.	5				1.	14
			1.	5				.2	3
			1.	8				.2	4
			1.	10				.1	3
			.5	9				.1	3
			.5	17				.1	10
			.1	6				.2	14
			.1	9				.1	4
			.07	52				.2	11
								.1	7
								.1	10
								.1	21
								.06	29
Result.	65.7	68.27	8.25	141	Result,	66.3	68.56	8.56	183

A circumstance which deserves attention in examining this table, is, that a few hundredths of a degree in rise of temperature, often required, at the commencement of an experiment, a much longer time than in the periods immediately following. In fact, it was sometimes observed, that the plunging of the hot iron into the water, was accompanied by an instantaneous minute depression of the liquid in the thermometer; subsequent to which, a stationary period occurred, and then a rapid rise—as indicated by the observations in the accompanying table. This phenomenon is to be ascribed to the sudden expansion of the glass composing the bulb of the instrument, by the first impression of the heat, affording an enlarged cavity for the liquid, before the latter begins to feel the same influence, and consequently to expand. This effect is the more striking, the greater is the difference of temperature to which the instrument is suddenly exposed. It needs hardly be mentioned that the opposite effect of a rise in the liquid,

accompanies the sudden immersion of the thermometer in a mass of fluid colder than itself.

It is also worthy of remark, that the time required by the thermometer to attain the same final temperature as the liquid in which it is plunged, is greater than that employed by the iron in giving up its excess of heat to the same liquid. This will generally require some deduction from the total observed time, in order to arrive at the true time of cooling of the standard piece.

The deduction will be less, the more sensible is the thermometer. Experiments with thermometer B, require less correction than those made with A, and the latter less than those with C.

Owing to the fact just stated it is not always easy to determine the precise moment when observations ought to cease; consequently, the last rise noted may, for our present purpose, often be rejected, when the amount observed does not exceed 5 or 6 hundredths of a degree, and the remaining time taken as the true duration of the cooling. By the aid of these observations, we shall be enabled to determine, very nearly, the relation between the respective *augmentations* of temperature in the water, and the *times* in which they severally occur. The more exact determination would require that the standard piece and the thermometer should be either both rapidly moving, or both at rest in the same relative positions, for every experiment. It was easily perceived that no slight influence might, in the earlier parts of the process, be ascribed to these circumstances.

An inspection of the table, shows that the general relation to which we have referred, is such, that *two-thirds of the change of temperature in the water, occurs during the first-third of the entire period of observation* This supposes the proper *correction* to have been applied to the latter as above pointed out.

Thus in experiment 3, table VIII., thermometer C gave a change of temperature 6.98°, two-thirds of which is 4.66°. During the time of the 10th observation, the rise of temperature came to 4.66°, and the time then elapsed was 84″ from the beginning, the *whole time* being 251″. Difference .33″.

In table VI., experiment 3, with the same thermometer, we have a total rise of 5.78° in 249″. Two-thirds of 5.78° is 3.85°, and one-third of 249″ is 83″. It appears that a rise of 3.85° had been attained during the sixth observation, and that at the moment when this took place, the time elapsed was 78.7″. Difference 4.3″

Again in table V., experiment 2, with the same thermometer, the total time was 290″; but the last observation gave a change of only $\frac{1}{100}$ of a degree in 37″. This being omitted, we have the time 253″, and the change 5.61°, two-thirds of which is 3.74°. One-third of the time is 84.3″. The observations prove that a rise of 3.74° took place during the 5th observation when the total time elapsed was 79.58″. Difference 4.72″.

When thermometer A was used, in experiment 5, table VI., a gain of 5.71° took place in 154″. The last $\frac{2}{100}$ of a degree required 11″; this being omitted, we have 5.69° in 143″. Two-thirds of 5.69 is 3.78; which by observation was attained in 44″, whereas the calculation would give 47.6″. Difference 3.6″.

With the same thermometer used in experiment 10, table VII., it appears that the total time, exclusive of 29″ taken up in rising through the last $\frac{6}{100}$ of a degree, was 154″, one-third of which is 51.3″. The total rise in this time was 8.5°, two-thirds of which is 5.67°, which by observation was attained in 46″. Difference 5.3″.

The thermometer B, of which the action was more prompt than that of either of the others, gives results more nearly agreeing with the law above stated. Thus in table IV., experiment 24, we find a rise of 4.6° in 94″. Two-thirds of 4.6° is 3.06°, and one-third of 94″ is 31.3″. By observation 3.06° had been attained in a trifle less than 30″. Difference 1.3″.

Again, in table VIII., experiment 2, a rise of 7.4° took place in 109″, one-third of which is 36.3″. The observation shows that a rise of 4.72° had been attained in 37″. Difference .7″.

If in table VII. experiment 4, thermometer A, we omit the time of the last observation, we have a gain of 8.36° in 103″.—Two-thirds of 8.36° is 5.57°, this rise of temperature had occurred at the end of 35″ by observation—whereas by calculation we should have 34.3″. Difference .7″.

In table VII. experiment 5, we obtained a gain of 8.25° of temperature in 141″. Two-thirds of 8.25° is 5.5°. This last number of degrees had been gained by the water about the middle of the 6th observation, or when the time from the commencement was 34″. As the last $\frac{7}{100}$ of a degree required 52″, we may safely attribute to the sluggishness of the thermometer the same retardation as in the preceding experiment; in which case we should have the total time 107″, one-third of which gives the calculated time for a rise through two-thirds the range equal to 35.6″, and the difference between the observed and the calculated times=1.6″.

In table VII. experiment 6, two-thirds of the gain of temperature was observed to have taken place at the end of 37″. The total time during which observations were made, was 125″, and as this time is much less than either of the two preceding, we may suppose that a less allowance is required for the tardiness of the thermometer, in consequence, perhaps, of more rapid agitation in the liquid while the latter received its augmentations of temperature. Hence if we deduct 15″ we have remaining 110, one-third of which is 36.6″ for the calculated time of attaining two-thirds of the gain of temperature. Difference .4″.

In table IV. experiment 25, we found that a gain of 4.7° was effected in 145″, the last 18 of which were taken up in raising the thermometer B. $\frac{5}{100}$ of a degree. Omitting this period, we have a remainder of 127″, one-third of which is 42.3″. Two-thirds of 4.7° is 3.14°, which, on inspecting the column of *rise of temperature*, we find was produced in 38.8″ from the time of beginning. Hence the calculated exceeds the observed time by 3.5″.

Of these eleven comparisons it will be observed that eight give the time by observation for two-thirds rise of temperature less, by a small amount, than one-third of the total time, while the others give the former greater than the latter quantity. The mean result, however, is a difference of only 1.5″. The results might probably be found to conform more exactly to the law, if the liquid were indefinite in quantity, and its rise indefinitely small, compared with the number of degrees through which the iron cooled.

Heating by Contact of Air.

The result just obtained, combined with another on the rate of heating of the vessels of liquid exposed to the action of air, will show on which of the experiments the greatest reliance is to be placed, as exhibiting the true specific heat of iron, without requiring a deduction for the influence of air.

The manner of performing these experiments, has been already adverted to. It consisted merely in filling the cylinders with water of a low temperature, and inserting in them, the same thermometers which had been used in experiments on specific and latent heat; placing other thermometers outside of the cylinders, to mark the temperature of the air.

The time of arriving at, and of leaving each mark on the scale, was then noted; and the mean taken as the point of time for attaining each degree.

Table XV. contains the result of these observations. The first 9 are, perhaps, from the particular attention directed to them, deserving of the most confidence, and from these it appears that *the rate of heating or of cooling, of a mass of liquid acted on by the air at a higher or a lower temperature, is directly and simply proportional to the difference of temperature between the liquid and the air.**

This is no more than a verification of the Newtonian law which is well known to be sensibly true only for very moderate differences, such as those observed by the committee which never exceeded 20°. The same law is also well known to fail entirely, when carried to very great differences. Assuming then the correctness of our result it enables us to determine, that while the iron in experiments on specific heats, was imparting its excess of heat to the water, *the air gave to the liquid as much heat as it received from it, whenever the initial temperature of the water was twice as much below that of the room as the final temperature was above it.*

* This results from a mean of 14 comparisons between the differences of temperature, and the corresponding times of heating through a given indefinitely small range of temperature, as one-tenth of a degree, by the formula $D^x : d^x : : t : T$. Where D and d are observed differences of temperature, between the water and the air, t and T the corresponding numbers of seconds required to raise the temperature 0.1°; and x the power of the difference of temperature according to which the times vary. These fourteen comparisons give a mean value of $x = 1.002$.

TABLE XV.

Comparative table showing the rate of heating or of cooling of given liquid masses in vessels of different sizes, by exposure in an atmosphere of known temperature.

No. of the Experiment.	DATE.	Weight of water.	Kind of containing vessel.	Initial temperature of the water.	Initial temperature of the air.	Final temperature of the water.	Final temperature of the air.	Mean difference of the air and water.	Time elapsed during the observation.	Amount of change in temperature.	Time required to produce a change of 1-10 of a degree.	Remarks.
	1835.											
1	Jan. 10.	20432	thin glass cylin. wght 3325 grs.	69°.7	63.°	69°.2	63.°	6°.45	640.″	–°.5	128.″	Thermometer B. mercurial = 43.7 grains of water.
2	..	20432		69.8	62.2	69.4	62.2	7.4	460.	–°.4	115.	
3	Jan. 17.	20432		41.	61.5	42.	61.5	20.	435.5	1.°	43.55	
4	..	20432		42.	61.5	44.	61.6	18.55	895.	2.	44.75	
5	..	20432		44.	61.6	46.	61.8	16.7	945.5	2.	47.25	
6	..	20432		46.	61.8	48.	61.8	14.8	1302.	2.	65.1	
7	..	20432		48.	61.8	50.	61.6	12.7	1273.5	2.	63.675	
8	..	20432		50.	61.6	52.	61.5	10.55	1534.	2.	76.7	
9	..	20432		52.	61.5	54.	61.9	8.7	1912.5	2.	95.625	
	1834.											
10	Dec. 8.	20274		70.2	74.5	70.3	74.5	4.25	37.5	.1	37.5	During this and the 3 following a brisk fire was kept up in the stove.
11	..	20274		70.4	73.	70.5	73.	3.55	35.	.1	35.	
12	..	20275		70.75	73.	70.85	73.	2.20	40.	.1	40.	
13	..	20275		70.5	73.	71.6	73.	1.45	45.	.1	40.	
14	..	20275		69.15	73.5	69.25	73.5	4.32	25.	.05	50.	
	1835.											
15	Mch, 22.	12676	thin iron cylin. 1733 grs.	50.93	64.	51.	64.	13.03	40.	.07	57.	The largest therm. (A) was used in this & 4 following = 196 grs. water. Water vessel in tin one, 14 inches high.
16	..	12676		51.	64.	51.1	64.	12.95	101.	.1	101.	
17	..	12675		51,1	64.	51.2	64.	12.85	125.	.1	125.	
18	..	12675		51.2	64.	51.3	64.	12.75	109.	.1	109.	
19	..	12675		51.3	64.	51.5	64.	12.6	175.	.2	87.5	
20	Feb. 21.	16728	thin glass jar 2996 grs.	55.975	57.	55.99	57.3	1.018	103.	.015	687.	In this & 9 following expts. the spirit thermometer C was used.
21	..	16728		55.99	57.3	56.035	57.6	1.287	63.	.045	140.	
22	..	16728		56.035	57.6	56.05	57.0	1.557	35.	.015	233.	
23	..	16728		50.05	57.9	56.06	58.2	1.845	65.	.01	650.	
24	..	16728		56.06	58.2	56.09	58.5	2.125	172.	.03	573.	
25	..	16728		52.29	58.5	52.33	58.5	6.29	126.	.04	315.	
26	..	16728		52.33	58.5	52.44	58.5	6.115	72.	.11	65.	
27	..	16728		52.44	58.5	52.50	58.5	6.03	60.	.06	100.	
28	..	16728		52.50	58.5	52.55	58.5	5.975	107.	.05	214.	
29	..	16728		52.55	58.5	52.61	58.5	5.91	68.	.06	213.	
30	Feb. 7.	12676	thin iron cylin. 1733.	59.7	68.	59.8	68.25	8.375	61.	.1	61.	Therm. B. No enclosing tin cylinder used.
31	..	12676		59.8	68.25	59.9	68.25	8.40	47.	.1	47.	

Strength of rolled copper.

Tables numbered from XVI. to XXIII. inclusive present the results of experiments on the strength of boiler copper, both at ordinary and at elevated temperatures. From these tables it appears that at temperatures varying from 62 to 82 degrees Fah., the strength of rolled copper is by a mean obtained from 66 experiments on 8 different specimens within those limits, equal to 32826 pounds to the square inch. The *irregularities* of strength vary in the different specimens from $1\frac{9}{10}$ to $4\frac{8}{10}$ per cent. of the mean tenacity of the specimen in which they occur, and the mean value for the 8 bars is $3\frac{3}{10}$ per cent. The strips of copper as received from the manufacturers were of 4 different thicknesses, two of each thickness, and they were reduced by filing to a nearly uniform size throughout their whole length. By an attentive observation, it will be seen that the thicker specimens give in general the higher results.

Thus, No. 1, of which the original thickness was two-tenths of an inch, (called by the manufacturers three-sixteenths,) broke at eight trials, with an average force of 30704 lbs. per square inch.

No. 2, with the same thickness, broke with 31468 lbs. as the average weight, at seven different trials. Hence the mean strength of these two bars is 31086 lbs. per square inch.

Nos. 3 and 4, the thickness of which was a "*scant quarter*" of an inch, broke, the former at ten trials, with 33428 lbs., and the latter at six trials, with 33243 lbs., giving a mean of 33335.

Nos. 6 and 7, having a thickness differing but little from the two preceding, but rather greater, gave, the one at seven trials, 33411, and the other at nine, 33005 lbs. per square inch ; or, as a mean of the two specimens, 33205.

Nos. 5 and 8, with a thickness before filing of not less than .27 of an inch, exhibited a tenacity of 33771 and 33780 lbs., the former being the mean of eleven and the latter of eight successive trials, showing a mean of 33775.

The manufacturers have not, in their note accompanying the specimens, referred to any difference either in the kind of pig metal, the melting and refining which took place previous to rolling, or in any other circumstance attending the manufacture of the different bars, which could lead the committee to assign a probable cause for the difference in point of cohesion between the respective pairs.

That difference between Nos. 5 and 8, and 1 and 2, is no less than 3071 lbs. per square inch, or 9.3 per cent. of 32836, which we have found to be the average strength of eight specimens.

But, as already stated, the irregularities observed in any one specimen, did not exceed $4\frac{8}{10}$ per cent. of its mean strength. It seems therefore probable, that in reducing the lighter specimens to their final thickness, the operation was extended so far as to reduce below a proper point the temperature of the copper, and thus to injure its texture. It will be seen that the highest results obtained by the committee, are almost identical with that given by Mr. Rennie.

In every calculation of the strength of materials for a steam boiler, the *least strength* known to be possessed by any part of the sheet, is that which alone can be relied on for fixing the pressure to which it may be subjected.

For *copper*, at ordinary temperatures, the lowest result obtained by the committee was 30406 lbs. per sq. inch, and the mean minimum for the 8 bars 32146 pounds. To other temperatures subsequent developements apply.

TABLE XVI.

Experiments on copper bar No. 1, manufactured by John M'Kim, Jr., & Sons of Baltimore, from South American pig, melted, refined and rolled into boiler-plate $\frac{3}{16}$ inch thick;—cut off with the shears one

Marks.	Breadth.	Thickness.	Area of sections at the points measured before trial.	No. of the Experiment.	DATE.	Area of the sections of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
0	.753	.192	.144576		1833.	sq. in.	°	lbs.		
1	.751	.189	.141939	1	Nov. 7.	.146412	57.5	159.5	4785	239.
2	.751	.194	.145694							
3	.750	.196	.147000							
4	.750	.196	.147000							
5	.752	.196	.147392							
6	.758	.196	.146608	2	"	.146711	120.?	154.	4620	231.
7	.748	.198	.148104							
8	.748	.197	.147356							
9	.748	.197	.147356							
10	.748	.197	.147356							
11	.747	.197	.147159	3	"	.144836	100.?	156.5	4695	234.7
12	.747	.196	.146412							
13	.746	.195	.145470							
14	.745	.196	.146020	4	"	.145015	95.?	154.5	4635	231.7
15	.745	.195	.145275							
16	.743	.197	.146371	5	"	.147114	90.?	157.	4710	235.5
17	.743	.198	.147114							
18	.746	.195	.145470	6	Nov. 9.	.147000	392.	135.	4050	202.5
19	.744	.195	.145080							
20	.743	.195	.144885							
21	.743	.195	.144885	7	"	.143407	75.	153.	4590	229.5
22	.742	.195	.144690							
23	.742	.196	.147392							
24	.747	.196	.146412	8	Nov. 14.	.147356	392.	135.125	4054	202.7
25	.747	.196	.146412							
26	.743	.197	.146371							
27	.742	.196	.147392	9	"	.147356	68.75	157.5	4725	236.2
28	.740	.196	.145040							
Mean of 29=			.146146	10	"	.145705	68.75	159.75	4792.5	239.62
Maximum			.148104							
Minimum			.141939	11		.146706	69.	159.	4770	238.5
Mean of the 2			.145021		Mean of 11 =	.146147				
Diff. of the 2			.006165							

TABLE XVI.

{ *inch wide, filed to the size recorded, marked and gauged at every inch. Specific gravity* 8.9866.

Effective strain.	Strength in pounds per square inch.	Weights producing extension.	Extension observed.	Point of fracture.	REMARKS.
4546.	31049	112. 119. 141.5	None. $\frac{1}{30}$ inch. 1 inch.	No. $24\frac{1}{2}$	The piece broken off had been elongated from 7 to 9.6 inches = 1 inch for every 2.69.
4389.	29916			" $26\frac{1}{3}$	Heated probably to the temperature noted, by the machine which had been used in a hot experiment just before this trial, fracture took place in the piece stretched in the preceding experiment.
4460.3	30795			" $21\frac{1}{4}$	Fracture oblique across the thickness of the bar.
4403.3	30364			" $19\frac{1}{3}$	Same piece as above.
4474.5	30415			" 17	
3847.5	26173			" $3\frac{3}{4}$	Part in hot oil from $2\frac{1}{2}$ to $5\frac{1}{2}$.
4360.5	30406			" $0\frac{1}{2}$	
3851.3	26136			" 9	
4488.8	30467			" 10	
4552.88	31247			" $12\frac{3}{4}$	
4531.5	30888			" $5\frac{7}{8}$	The mean area of the 11 sections of fractures is .000001 square inch greater than the mean area of the 29 measured sections.

TABLE XVII.

Experiments on copper bar No. 2, manufactured by John M'Kim, jr., & Sons, of Baltimore, from South American pig, melted, refined and rolled into boiler plate three-sixteenths of an inch thick, cut off with the

Marks.	Breadth.	Thickness.	Area of section before trial.
0	.723	.198	.143154
½	.713	.198	.141174
1	.724	.197	.142628
1½	.735	.197	.144795
2	.720	.196	.141120
2½	.721	.194	.139874
3	.742	.199	.147658
3½	.745	.200	.149000
4	.744	.195	.145080
4½	.722	.195	.140790
5	.719	.195	.140205
5½	.720	.195	.140400
6	.720	.200	.144000
7	.720	.195	.140400
8	.724	.198	.143352
9	.728	.199	.144872
10	.732	.197	.144204
11	.732	.197	.144204
12	.736	.200	.147200
13	.739	.198	.146322
14	.738	.198	.146124
15	.737	.198	.145926
16	.732	.198	.144936
17	.720	.198	.142560
17½	.713	.197	.140461
18	.713	.196	.139748
19	.714	.196	.139944
20	.723	.197	.142431
21	.729	.200	.145800
22	.728	.198	.144144
23	.729	.199	.145071
24	.728	.199	.144872
25	.735	.197	.144795
26	.737	.200	.147400
27	.730	.199	.145270
Mean of 35 =			.143711
Maximum			.149000
Minimum			.139748
Mean of the 2 =			.144374
Diff. of the 2 =			.009252

DATE.	No. of the Experiment.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
1833, Dec. 31,	1	.139895	63.5	153.5	4605.	230.
1834. Jan. 4,	2	.145446	32.	159.75	4792.5	239.
"	3	.143273	32.	160.25	4807.5	240.
"	4	.140451	32.	159.	4770.	238.5
"	5	.143023	32.	159.	4770.	238.5
"	6	.140400	32.	159.	4770.	238.5
"	7	.142560	32.	159.	4770.	238.5
"	8	.143352	32.	161.	4830.	241.5
"	9	.145926	32.	161.	4830.	241.5
Jan. 11.	10	.141424	62.5	158.25	4747.5	237.
"	11	.144872	62.5	159.5	4777.5	238.
"	12	.144872	62.5	160.	4800.	240.
"	13	.146868	62.5	163.25	4897.5	244.
"	14	.145702	62.5	160.25	4807.5	240.
"	15	.146075	62.5	160.25	4807.5	240.
Mean of 14 =		.143519				

TABLE XVII.

shears one inch wide, filed to the size recorded, marked and gauged at every inch, and in some parts to every half inch. Specific gravity 8.9866.

Effective strain.	Strength in pounds per square inch.	Temp. of the room.	Weight producing elongation before fracture.	Elongation observed.	Point of fracture.	REMARKS.
4375.	31273		lbs. 112. 126. 133. 140. 143.5 147. 153.5	1st permanent .35 inch 1.12 " 2.00 " 2.50 " 3.10 " Broke.	No. $18\frac{3}{4}$	The filing of this bar being less accurate than of others it was gauged in part at half inch distances. The space between the wedges, and on which the elongations were measured, was 25 inches.
4553.5	31307	59°.5			$25\frac{1}{4}$	Part in *ice* from 22 to 25. Broke just without the *ice*.
4567.5	31870	59.			$20\frac{1}{4}$	The part fractured must have been between 59° and 32°—same part in ice as above.
4531.5	32264	59.			$17\frac{3}{4}$	Part in ice from 8 to 11 inclusive.
4531.5	31684	59.			$0\frac{1}{4}$	Part in ice from 11 to 14 inclusive.
4531.5	32272	59.			$5\frac{1}{2}$	Do.
4531.5	31787	59.			17	Broke near the end.
4588.5	32007	59.			8	Part in ice from 10 to 13 inclusive.
4588.5	31444	59.			15	Broke outside of the ice. No fracture has taken place *in ice*.
4510.5	31893				$4\frac{3}{4}$	The following experiments were made on the remaining short pieces at the temperature of the room, not being long enough for trial in ice.
4539.5	31334				24	Reduced but not broken at 24. When it appeared about to break, $5\frac{1}{4}$ lbs. were taken off to prevent immediate fracture. One pound restored broke the bar instantly.
4560.	31476				24	
4653.5	31685				$26\frac{1}{4}$	
4567.5	31348				$11\frac{1}{2}$	
4567.5	31268				$14\frac{1}{4}$	The mean area of the 14 sections of fracture is .000192 sq. inch less than the mean area of the 35 measured sections.

TABLE XVIII.

Experiments on copper bar No. 3., manufactured by John M'Kim, Jr., & Sons, of Baltimore, from South American pig, melted, refined and rolled into boiler plate, scant ¼ of an inch thick; cut off with the

Marks.	Breadth.	Thickness.	Area of section before trial.	DATE.	No. of experiment.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.
0	.708	.245	.173460	1833.	1	.164000	65.5	193.75
1	.708	.245	.173460	Dec. 8.				
2	.700	.245	.171500					
3	.695	.244	.169580	"	2	.166970	65.5	194.75
4	.686	.246	.168756					
5	.678	.241	.163398					
6	.688	.241	.165808	"	3	.169031	65.5	195.25
7	.690	.243	.167670					
8	.695	.245	.170275					
9	.700	.244	.170800	"	4	.171260	65.25	195.25
10	.700	.245	.171500					
11	.700	.240	.168000					
12	.700	.243	.170100	"	5	.173460	66.	196.5
13	.710	.240	.170400					
14	.710	.242	.170820					
15	.710	.246	.174660	"	6	.168000	122.	194.25
16	.712	.243	.173016					
17	.712	.244	.173728					
18	.712	.243	.173016	Dec. 15.	7	.170800	56.	195.
19	.711	.242	.172062					
20	.712	.243	.173016					
21	.712	.241	.175992	"	8	.165808	56.	195.25
22	.713	.245	.174685					
23	.713	.244	.173972					
24	.713	.243	.173259	"	9	.170760	124.	201.75
25	.713	.240	.171120					
26	.711	.240	.170640					
27	.708	.238	.168504					
				Dec. 22.	10	.173700	124.	198.75
		Mean of 28 =	.171028					
		Maximum	.174685	"	12	.172062	126.	199.75
		Minimum	.163398					
		Mean of the two	.169041	"	11	.172541	61.5	201.25
		Diff. of the two	.011287	"	13	.173259	61.5	200.
				"	14	.173372	61.5	198.75
					Mean of 14 =	.170358		

TABLE XVIII.

shears one inch wide, filed to the size recorded, marked and gauged at every inch. Specific gravity 8.7891.

Breaking weight X leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Point of fracture.	REMARKS.
5812.5	290.6	5521.9	33670	No. $5\frac{1}{4}$	
5842.5	292.61	5550.4	33242	" $4\frac{1}{3}$	
5857.5	292.8	5564.7	32921	" $3\frac{1}{3}$	
5857.5	292.8	5564.7	32494	" $2\frac{7}{8}$	
5895	294.7	5600.3	32286	" $0\frac{1}{4}$	
5827.5	291.3	5536.2	32949	" 11	Nos. 11, 12 and 13 in oil bath.
5750	292.5	5557.5	32538	" 9	A part which had been griped by the wedges remained unbroken, betraying no unusual weakness.
5857.5	292.87	5564.8	33561	" 6	Broken where it had been griped before.
6052.5	302.6	5749.9	33672	" $25\frac{3}{4}$	Broke *in oil.*
5962.5	298.1	5664.4	32610	" $14\frac{3}{4}$	Broke just outside of the oil bath—part included being from 15 to 18.
5992.5	299.6	5692.9	33086	" 19	Broke *in the oil.*
6037.5	301.8	5735.7	33242	" $20\frac{1}{3}$	
6000	300	5700	32899	" 24	
5962.5	298.1	5664.4	32672	" $17\frac{1}{2}$	Torn off by the wedges.
					The mean area of the 14 sections of fracture .000670 square inch *less* than the mean area of the 28 sections measured.

TABLE XIX.

Experiments on copper bar No. 4. Manufactured by John M' Kim, Jr., and Sons of Baltimore, from South American pig, melted, refined and rolled into boiler plate, scant ¼ of an inch thick, cut off with the

Marks.	Breadth.	Thickness.	Area of section before trial.	Elastic. tried before 1st frac.			
				Weight producing elongation.	Total recoil.	Elasticity of the machine.	Elasticity of the bar.
0	.717	.240	.172080	10¼	10		
1	.717	.240	.172080	17¼	20		
2	.717	.240	.172080	24¼	30		
3	.717	.237	.169929	31¼	38½		
4	.715	.237	.169455	38¼	44		
5	.715	.237	.169455	45¼	52		
6	.711	.237	.168507	52¼	57		
7	.718	.237	.170166	56	59½		
8	.721	.237	.170877	63	68		
9	.725	.237	.171825	70	73		
10	.728	.237	.172536	77	79		
11	.729	.237	.172773	84	87½		
12	.732	.237	.173484	91	93		
13	.732	.237	.173484	May 3d, 1834. 98	97		
14	.732	.237	.173484	105	102		
15	.732	.237	.173484	112	104		
16	.733	.240	.175920	119	114		
17	.735	.240	.176400	126	117		
18	.738	.240	.177120	133	125		
19	.740	.240	.177600	140	132		
20	.740	.238	.176120	143.5	128.5		
21	.740	.238	.176120	147	129		
22	.742	.241	.178822	154	133		
23	.743	.240	.178320	157½	144		
24	.748	.240	.179520	161	137		
25	.749	.240	.179760	164½	152		
26	.744	.240	.178560	164½	147⅓	100⅓	47′
27	.744	.240	.178560				
	Mean of 28 =		.174233				
	Maximum		.179760				
	Minimum		.168507				
	Mean of the two =		.174133				
	Diff. of the two		.011253				

The last of the above observations was made when the bar had been under strain one week, after which the extension in 27 inches had become $\frac{22}{100}$ of an inch.

The elasticity was now taken several times, the mean being 147⅓. The elasticity of the machine under the same weight, was found to be 100⅓ hence that of the copper bar was 47′.

DATE.	No. of the experiment.	Area of the section of fracture before trial.	Temperature Fahrenheit.
1834. May 10.	1	.169455	69$\overset{\circ}{2}$
"	2	.171914	844
May 17.	3	.175311	1016
"	4	.178147	1032
May 24.	5	.179700	81.5
"	6	.178560	81.5
"	7	.176160	81.5
"	8	.176490	81.5
"	9	.172358	81.
"	10	.173484	81.
"	11	.173484	81.
May 31.	12	.168981	69.5
"	13	.168922	69.5
"	14	.172080	69.5
Mn. of 14 =		.173932	

TABLE XIX.

shears one inch wide, filed to the size recorded, marked and gauged at every inch. Specific gravity 8.7388.

Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Point of fracture.	REMARKS.
130.5	3915.	195.7	3719.3	21948	No. 4.	The elasticities of the machine having been taken more than two years before these experiments were made, were found to have varied so much as to render useless any attempt to decide, from the trials now made, the successive elasticities of the bar.
101.5	3045.	152.2	2882.8	16768	" $9\frac{1}{8}$	
68.	2040.	102.	1938.	11054	" $15\frac{3}{4}$	
68.	2040.	102.	1938.	10878	" $21\frac{3}{4}$	
200.5	6015.	300.75	5714.25	31798	" $24\frac{3}{4}$	This part had been heated in a former trial.
203.25	6097.5	304.88	5792.62	32440	" $26\frac{1}{2}$	
200.	6000.	300.	5700.	32357	" $16\frac{1}{2}$	Heated at this section in experiment 3d.
200.	6000.	300.	5700.	32296	" $19\frac{3}{4}$	Heated in experiment 4th.
201.	6030.	301.5	5728.5	33236	" $9\frac{3}{4}$	Heated in experiment 2d.
201.25	6037.5	301.87	5735.63	33061	" $13\frac{1}{2}$	
201.75	6052.5	302.62	5749.88	33143	" 12	
196.25	5887.5	294.37	5593.13	33099	" $5\frac{1}{2}$	
198.5	5955.	297.75	5657.25	33490	" $6\frac{1}{4}$	
198.25	5947.5	297.37	5650.13	32834	" 1	
						The mean area of the 14 sections of fracture .000301 square inch *less* than the mean area of the 28 measured sections.

TABLE XX.

Experiments on copper bar No. 5. Manufactured by John M'Kim, Jr., & Sons, of Baltimore, from South American pig, melted, refined, and rolled into boiler plate full ¼ inch thick, cut off with the shears 1 inch

Marks.	Breadth.	Thickness.	Area of section before trial.		No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature. Fah.
0	.778	.260	.202280					
1	.774	.264	.204336			1834.		
2	.764	.265	.202460		1	Jan. 25.	.202407	472
3	.766	.263	.201458					
4	.768	.264	.202752					
5	.767	.267	.204789		2	Feb. 1.	.205279	472
6	.767	.267	.204789					
7	.767	.269	.206323		3	"	.201585	80
8	.767	.267	.204789					ap.
9	.768	.267	.205056		4	"	.204229	64
10	.770	.267	.205590					
11	.770	.267	.205590		5	"	.203846	64
12	.771	.267	.205857					
13	.771	.266	.205086		6	"	.203023	64
14	.770	.263	.202510					
15	.770	.265	.204050					
16	.773	.260	.200980		7	"	.203036	64
17	.772	.263	.203036					
18	.772	.263	.203036					
19	.772	.264	.203808		8	"	.206092	64
20	.772	.268	.206896					
21	.768	.268	.205824		9	Feb. 8.	.204280	482
22	.761	.267	.203187					
23	.758	.266	.201628		10	"	.202210	60
24	.755	.267	.201585					
25	.767	.265	.203255		11	"	.202929	60
26	.769	.266	.204554					
27	.770	.267	.205590		12	"	.204789	60
		Mean of 28=	.203967		13	"	.205790	60
		Maximum Minimum	.206323 .200980	.005343 differ.	14	"	.204789	60
		Mean of the 2=	.203651			Mean of 14=	.203877	

TABLE XX.

wide, filed to the dimensions recorded, marked and gauged at every inch. *Specific gravity* 8.7857.

Breaking weight in the scale.	Br. wt. × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.	Point of fracture.	REMARKS.
192.	5760.	288.	5472.	27034	No. $22\frac{1}{2}$	Part in oil from 20° to 24°. The thermometer was noted at the time 482, but on being re-graduated was found 10 degrees too high at this point.
195.75	5872.5	293.6	5578.9	27128	" $12\frac{3}{4}$	
238.5	7155.	357.75	6797.25	33719	" 24	
246.25	7387.5	369.87	7017.63	34361	" $25\frac{3}{4}$	
241.25	7237.5	361.87	6875.63	33729	" $21\frac{3}{4}$	
240.5	7215.	360.75	6854.25	33761	" $14\frac{1}{3}$	
241.75	7252.5	362.62	6889.88	33932	" $17\frac{7}{8}$	Fracture remote from the wedges.
242.75	7282.5	364.17	6918.33	33569	" $20\frac{3}{4}$	
191.75	5752.5	287.62	5464.88	26752	" $4\frac{3}{4}$	
240.75	7222.5	361.12	6861.38	33931	" $2\frac{1}{4}$	
240.75	7222.5	361.12	6861.38	33812	" $1\frac{3}{4}$	
241.	7230.	361.50	6869.5	33544	" 5	
241.75	7252.5	362.62	6889.88	33480	" $11\frac{3}{4}$	
241.75	7252.5	362.62	6889.88	33644	" 8	Sooner parted than the preceding. Weight may have been a trifle too great.
						The mean area of the 14 sections of fracture .000090 square inch *less* than the mean area of the 28 measured sections.

TABLE XXI.

Experiments on copper bar No. 6. Manufactured by John M'Kim, Jr., and Sons, of Baltimore, from South American pig, melted, refined and rolled into boiler plate, full ¼ of an inch thick, cut off with the

Marks.	Breadth.	Thickness.	Area of section before trial.	DATE.	Number of Experiment.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.
0	.737	.253	.186461	1834.				
1	.737	.253	.186461	Feb. 15.	1	.186113	545	166.
2	.736	.253	.186208					
3	.736	.253	.186208	"	2	.186271	70	213.5
4	.733	.253	.185449					
5	.733	.253	.185449					
6	.733	.253	.185449	"	3	.186461	66	215.25
7	.733	.253	.185449					
8	.733	.253	.185449					
9	.733	.253	.185449	Feb. 22.	4	.186043	561	163.5
10	.736	.253	.186208					
11	.736	.253	.186208					
12	.736	.253	.186208	"	5	.185449	71	210.5
13	.736	.253	.186208					
14	.735	.253	.185955	"	6	.185449	71	210.5
15	.735	.253	.185955					
16	.735	.253	.185955	"	7	.186208	70	214.5
17	.735	.253	.185955					
18	.735	.253	.185955					
19	.735	.253	.185955	"	8	.185955	801	123.
20	.735	.253	.185955					
21	.735	.253	.185955					
22	.735	.253	.185955	March 1.	9	.185955	62	216.75
23	.735	.253	.185955					
24	.735	.253	.185955	"	10	.185955	61	218.25
25	.736	.253	.186208					
26	.736	.253	.186208	"	11	.185955	60	219.75
27	.736	.253	.186208					
				"	12	.186208	59	219.75
Mean of 28 =			.185964					
Maximum			.186461	"	13	.186208	58	220.
Minimum			.185449					
Mean of the 2 =			.186455	March 8.	14	.185955	70	218.
Differ. of the 2 =			.001012		Mean of 14 =	.186013		

TABLE XXI.

shears one inch wide, filed to the dimensions recorded, marked and gauged at every inch. Specific gravity 8.9666.

Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Point of fracture.	REMARKS.
4980	249.	4731.	25420	No. $3\frac{7}{8}$	Broke in tin; part immersed (from 2 to 6 inclusive.)
6405	320.	6085.	32666	" $1\frac{3}{4}$	
6457.5	322.8	6134.6	32900	" 0	
4905	245.2	4659.8	25047	" $9\frac{3}{4}$	Broke in tin; part immersed from 8 to $11\frac{1}{2}$.
6315	315.7	5999.2	32350	" 8	Embraced in the preceding hot portion.
6315	315.7	5999.2	32350	" $5\frac{1}{2}$	Had been heated.
6435	321.7	6113.25	32830	" 27	Not tried before.
3690	184.	3506.	18854	" $18\frac{1}{4}$	Very little extended before fracture.
6502	325.	6177.	33218	" 20	A portion formerly gripped by the wedges, is embraced within this part of the bar, but does not give way, proving that the action of the machine on such parts does not weaken the material.
6547	327.	6220.	33443	" $21\frac{1}{2}$	
6592	329.	6263.	33682	" 23	
6592	329.	6263.	33634	" $25\frac{1}{2}$	Fracture at a place formerly heated.
6600	330.	6270.	33672	" 13	
6540	327.	6213.	33401	" $16\frac{1}{2}$	The mean area of the 14 sections of fracture .000049 *greater* than the mean area of the 28 measured sections.

TABLE XXII.

Experiments on copper bar No. 7. Manufactured by John M'Kim, Jr., and Sons, of Baltimore, from South American pig, melted, refined and rolled into boiler plate, full ¼ of an inch thick. Cut off with the }

Marks.	Breadth.	Thickness.	Area of sections at the points measured before fracture.
0	.743	.248	.184264
1	.743	.246	.182778
2	.744	.248	.184512
3	.744	.248	.184512
4	.744	.249	.185256
5	.743	.249	.185007
6	.743	.249	.185007
7	.743	.249	.185007
8	.742	.249	.184758
9	.742	.249	.184758
10	.742	.248	.184016
11	.742	.248	.184016
12	.742	.248	.184016
13	.742	.248	.184016
14	.742	.248	.184016
12	.742	.248	.184016
16	.742	.248	.184016
17	.742	.248	.184016
18	.742	.249	.184758
19	.742	.249	.184758
20	.742	.249	.184758
21	.743	.249	.185007
22	.743	.249	.185007
23	.743	.249	.185007
24	.743	.248	.184264
25	.743	.248	.184264
26	.743	.248	.184264
27	.740	.248	.183520
28	.743	.248	.184264

Mean of 29 = .184402

Maximum .185256 }
Minimum .182778 } .002478 Diff.

Mean of the 2 .184017

No. of Experiment.	DATE.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.
	1834.			
1	Apl. 19.	.185007	912	96
2	"	.184884	90 ap.	215
3	"	.184016	602	144
4	"	.184016	817	108
5	Apl. 26.	.184007	63	214
6	"	.184512	63	217
7	"	.184007	992	72
8	May. 24,	.184264	81.75	212
9	"	.183892	81.75	216.75
10	"	.184882	81.75	213.25
11	"	.184758	81.75	213.25
12	"	.184016	81.75	213.75
13	"	.184016	81.5	214.5

Mean of 13 = .184329

TABLE XXII.

shears one inch wide, filed to the size recorded, marked and gauged at every inch. Specific gravity, 8.8543.

Breaking weight X leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Point of fracture.	REMARKS.
2880	144	2736	14789	No. 5½	Part in tin from 3 to 6½.
6450	322	6128	33145	" 3½	
4320	216	4104	22302	" 11⅛	Part in metal 9 to 12 inclusive. The temperature recorded is supposed to be a little too low, as a short time elapsed after the fracture, before it was noted.
3240	162	3078	16727	" 17	
6420	321	6099	32966	" 8	
6510	325.5	6184	33515	" 3	
2160	108	2052	11091	" 23	Part in metal from 22 to 24½. As the surface of the copper was not oxidated before trial, this temperature caused some alloying which may have slightly diminished the strength.
6360	318	6042	32790	" 24¾	Probably a little weakened by the preceding high temperature.
6502.5	325.12	6177.38	33592	" 27½	
6397.5	319.87	6077.63	32819	" 20¾	
6397.5	319.87	6077.63	32895	" 18¾	
6412.5	320.62	6091.88	33105	" 16½	
6435	321.75	6113.25	33221	" 15	
					The mean area of the 13 sections of fracture .000073 square inch *less* than the mean area of the 29 measured sections.

TABLE XXIII.

Experiments on copper bar No. 8. Manufactured by John M'Kim, Jr., & Sons, of Baltimore, from South American pig, melted, refined, and rolled into boiler plate, full ¼ inch thick. Cut off with the shears

Marks.	Breadth.	Thickness.	Area of the sections measured before trial.
0	.766	.256	.196096
1	.766	.262	.200692
2	.766	.260	.199160
3	.768	.260	.199680
4	.769	.263	.202247
5	.770	.263	.202510
6	.767	.263	.201721
7	.768	.256	.196608
8	.764	.263	.200932
9	.766	.255	.195330
10	.766	.254	.194564
11	.768	.257	.197376
12	.766	.258	.197628
13	.766	.259	.198394
14	.768	.259	.198912
15	.768	.259	.198912
16	.769	.263	.202247
17	.772	.260	.200720
18	.772	.260	.200720
19	.772	.260	.200720
19½	.770	.260	.200200
20	.759	.258	.195822
20½	.751	.258	.193758
21	.755	.257	.194035
22	.762	.258	.196596
23	.765	.258	.197370
24	.764	.258	.197112
25	.765	.261	.199665
26	.761	.262	.199382
27	.762	.258	.196586
28	.757	.258	.195306
Mean of 31=.198420			
Maximum .202510			.008752 Diff.
Minimum .193758			
Mean of the 2=.198134			

No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature Fah.	Breaking weight in the scale.
	1833.			
1	Nov. 16.	.202510	212°	225.75
2	"	.201391	65.75	233.
3	"	.199290	65.75	233.
4	Nov. 21.	.197597	212.	226.
5	"	.197284	302.	215.
6	"	.199034	62.	229.
7	"	.197197	62.	233.5
8	"	.201721	64.	235.25
9	"	.197502	60.	238.
10	Nov. 23.	.194569	60.	238.
11	"	.202247	302.	217.75
12	"	.200720	65.	235.75
13	"	.198912	65.	235.75
14	"	.197525	65.	232.
Mean of 14=.199107				

TABLE XXIII.

1 inch wide, filed to the dimensions recorded, marked and gauged at every inch. *Specific gravity* 8.9285.

Br. wt. × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.	Point of fracture.	REMARKS.
6772.5	338.6	6433.9	31778	No. 5	Part in oil from $2\frac{1}{2}$ to $5\frac{1}{2}$.
6990.	349.5	6640.5	32973	" $3\frac{2}{3}$	May have been warmed by the machine.
6990.	349.5	6640.5	33321	" $2\frac{1}{4}$	
6780.	339.	6441.	32596	" $11\frac{7}{8}$	Part in oil from 11 to $14\frac{1}{2}$.
6450.	322.5	6127.5	31059	" $23\frac{1}{3}$	Part in oil from 22 to 25.
6870.	343.5	6526.5	32791	" $26\frac{1}{8}$	Probably somewhat heated by the machine.
7005.	350.25	6654.75	33749	" $8\frac{2}{3}$	The fractured part had been gripped in a former experiment, but showed no weakening from that cause.
7057.5	352.87	6704.63	33237	" 6	
7140.	357.	6783.	34343	" $11\frac{1}{2}$	
7140.	357.	6783.	34862	" 10	Broke with the same weight as the preceding, but with a slow motion.
6532.5	326.62	6205.88	30685	" 16	Part in oil from $15\frac{1}{2}$ to $18\frac{1}{2}$.
7072.5	353.62	6718.88	33474	" 17	
7072.5	353.62	6718.88	33783	" 14	Broke rapidly—weight appeared to be a little too great.
6960.	348.	6612.	33474	" $26\frac{2}{3}$	The mean area of the 14 sections of fracture .000701 square inch *greater* than the mean area of the 31 sections measured.

Effect of increased temperature on copper.

The effect of temperature on tenacity, has been hitherto but slightly examined, either for theoretical or practical purposes. The general truth that heat diminishes, and eventually overcomes cohesion, is too well established by daily observation to admit of question.

The temperature of *no tenacity*, is generally supposed to be that at which the fusing point of the given substance is placed, and the point of maximum tenacity ought, upon general principles, to be found at the point where least heat prevails, that is, at the natural zero, or point of *absolute cold*, if such a point exist in nature. Between these two extremes, it might be supposed that the tenacities of different substances, particularly such as are capable of passing immediately from the solid to the liquid state, would be found to obey certain laws. As the total cohesion at the maximum would present to a mechanical agent tending to overcome it, the whole of its resistance, and as, at more elevated temperatures, a part of that tenacity would be overcome by heat, and the rest must be destroyed by the mechanical force, it is evidently a question of experiment, to decide what relation the two forces have to each other at the several temperatures between the two extremes to which we have just alluded. To decide the theoretical question, or, in other words, to deduce, from the experiments, a law which might be expressed in an abstract form corresponding to all the possible phenomena, would require a state of the materials different from that usually found in commerce or employed in the arts. It would also, as we have seen, require a knowledge of that, about which philosophers no less than practical men, are far from being agreed;—namely, the point of absolute cold. As the purposes of this committee did not lead them to investigate the problem in all its *possible* bearings, but only in view of the limits which practice assigns, and with the conditions commonly given to the materials, it will not perhaps, be easy, to construct from the tables a formula in all respects unexceptionable.

The general course of experiments involved the necessity of operating, at the different temperatures, on different bars of copper, and as all the bars are not found to give, even at ordinary temperatures, the same strength, for equal areas of section, it became necessary to deduce from experiments on each bar, at some assumed low temperature, a standard tenacity with which to compare its strength at every other point. The part of this *standard tenacity* which was taken away by the heat at the higher temperatures, becoming known by the experiment, a comparison was furnished for deciding approximately the relation between the temperature given, and the portion of tenacity which it had overcome. It will be found on an inspection of Table XXIV. containing the comparison of these experiments, that on the eight different bars, the whole number of trials which furnished standards of comparison, at ordinary temperatures, was sixty-six, and consequently on an average about eight trials to each bar; while at the elevated temperatures there were made thirty-nine different experiments at nineteen different points on the scale, the greater number of points, however, having but one experiment each.

An inspection of plate IX., where these experiments are represented, will show that at nearly all parts of the scale, within which the trials were made, the strength diminishes more rapidly than the temperature increases, but some of the higher experiments indicate that the conditions of the law are such as to be represented by a curve, having a point of inflection. It will

also be observed that the three experiments which appear anomalous, and which in the plate are marked with queries, are all found in trials of the same bar of copper, (No. 7,) and that all these might be referred to a curve, varying but little in form from that which we have traced. It is not however *necessary* to suppose that these experiments belong to a different curve, for upon recurring to the table of bar No. 7. (Table XXII.) it will be found that one of the anomalies is satisfactorily accounted for by a delay in taking the temperature after the fracture had occurred, and that one of the others and probably both, were cases of weakening by a slight alloying of the copper by the melted metal through which it passed, in consequence of not having been defended by oxide. The other bars tried at high temperatures were treated with dilute nitric acid, creating a thin film of oxide, which effectually defended the surface, without sensibly diminishing even the smoothness of the bar.

It will be observed that the difference of tenacity, at the *lower temperatures*, for a difference of from 60 to 90 degrees, is scarcely greater than the actual *irregularities* of structure in the metal at common temperatures, and consequently, it was not practicable from these experiments alone to deduce a law which should express the tenacities at all points between the maximum above referred to, and the melting point of the metal. Nor would much confidence probably have been reposed in results thus obtained.

In laying down the results in plate IX., the line $a\ b$ is made to represent the total tenacity of copper at 32°. The horizontal dotted lines express the observed temperatures above 32°, and the vertical ones, the diminutions of tenacity at the respective points.

In examining the eleventh and twelfth columns of Table XXIV., with a view to a relation which may afford a practical rule for calculating the strength of copper at any given temperature, it will be found, that with the exception of the three anomalous cases, Nos. 11. 14, and 17, of the table, they may be referred to a species of parabola, of which the ordinates representing the temperatures above 32°, have to the abscissas representing the diminutions of tenacity, a relation expressed by *the cube roots of the squares* of the latter quantities; or, in other words, that the *squares of the diminutions are as the cubes of the temperatures.**

* To determine whether any, and if any, what, single function of the temperature will at any point express the diminution of strength, as compared with that observed at other points, it was not deemed expedient to rely on a single comparison. The following method was, therefore, employed to obtain an expression corresponding with each of fourteen different points, compared with thirteen others. Putting $t =$ any observed temperature above 32°; $t' =$ any other temperature above the same; $d =$ the diminution of tenacity by the former temperature, and $d' =$ that by the latter: also $x =$ the power of the temperature, according to which the diminution of tenacity varies, we have $t^x : t'^x :: d : d'$ whence $\frac{t'^x}{t^x} = \frac{d'}{d};$ from which we get $x = \frac{Log\ d' - Log\ d}{Log\ t' - Log\ t.}$ Thus at a temperature of ~~984~~ 1016° Fah., the tenacity was 1016 found by experiment to have been diminished .6691, its amount at 32° being 1.0000; and its diminution at 492° was .2133; hence by the above formula, $\frac{Log\ .6691 - Log\ .2133}{Log\ (984-32) - Log\ (492-32)} = 1.503.$

TABLE XXIV.

Experiments relative to the effects of temperature on the strength of rolled copper—made on the different bars subjected to trial during this investigation, the absolute strength being derived from a number of experiments on each bar, and the mean results of these furnishing for each separate bar a standard of comparison for the strength at high temperatures.

No. of the compar.	Temp. obs. at the time of fracture.	No. of exp. at each tem.	Str'gth in lbs. Avoir. per sq. inch at each tem.	No. of the bar on which the experi. was made.	Temp. at which expt. were made for compar.	No. of ex. on which the comp. cold str'gth is founded.	Strength at ordinary temp.	Ext. variation among the several experi.	Calculated strength at 32 degrees.	Elevation of temp. above 32 degrees.	Diminution of tenacity in parts of the str'gth at 32 deg.	Diminution of tenacity as calcula. from the law deduced.	Difference of calculated and observed results.	Original thickness of the plate.	Mean area of section at the points of fracture in each bar.	REMARKS.
1	32°	8	31830.5	2	62.°	7	31468	.032	31830.5	0.°	.0000	.0000	+.0000	3/16 inch	.143519	It is probable that the diff. .0073 between the strength at 32°, and that at 62° may be a little too great, but the nature of the law of decrease in strength will not be essentially affected by the excess.
2	62	7	31466.	2	62.	7	31468	.032	31830.5	30.	.0073	.0101	+.0028	3/16 do.	.143519	
3	122	4	33079.	3	62.	10	32428	.041	33671.	90.	.0175	.0182	+.0007	1/4 scant	.170358	
4	212	2	32187.	8	64.	8	33780	.048	34025.	180.	.0540	.0515	—.0025	1/4 full	.199017	As all the fractures except one at this temperature were in the hot bath, the strength is doubtless diminished by this temperature 212°.
5	302	2	30872.	8	64.	8	33780	.048	34025.	270.	.0926	.0945	+.0019	do.	.199017	
6	392	2	26154.	1	70.	8	30704	.028	30934.	360.	.1513	.1456	—.0057	3/16	.146147	
7	482	2	27081.	5	62.	11	33771	.026	34008.	450.	.2046	.2035	—.0011	1/4 full	.203877	
8	492	1	26752.	5	62.	11	33771	.026	34008.	460.	.2133	.2101	—.0032	do.	.203877	
9	545	1	25420.	6	62.75	7	33411	.022	33655.	513.	.2446	.2477	+.0031	do.	.186013	
10	561	1	25047.	6	62.75	7	33411	.022	33655.	529.	.2558	.2594	+.0036	do.	.186013	
11	602 ?	1	22302.	7	81.5	9	33005	.045	33473.	570. ?	.3307 ?	.2901	—.0406	do.	.184329	
12	692	1	21948.	4	75.25	6	33143	.019	33384.	660.	.3425	.3616	+.0190	1/4 scant	.173932	
13	801	1	18854.	6	62.75	7	33411	.022	33655.	769.	.4398	.4546	+.0148	1/4 full	.186013	
14	817 ?	1	16727.	7	81.5	9	33005	.045	33473.	785. ?	.5003 ?	.4689	—.0314	do.	.184329	
15	844	1	16768.	4	75.25	6	33143	.019	33304.	812.	.4944	.4932	—.0012	1/4 scant	.173932	
16	912	1	14789.	7	81.5	9	33005	.045	33473.	880.	.5581	.5565	—.0016	1/4 full	.184329	
17	992 ?	1	11091.	7	81.5	9	33005	.045	33473.	960. ?	.6686 ?	.6341	—.0345	do.	.184329	
18	1016	1	11054.	4	75.25	6	33143	.019	33384.	984.	.6691	.6588	—.0103	1/4 scant	.173932	
19	1032	1	10878.	4	75.25	6	33143	.019	33384.	1000.	.6741	.6741	+.0000	do.	.173932	

Note.—By an inspection of the above table it will be seen that at a temperature of about 550° Fah. copper loses one-fourth of its *tenacity at ordinary temperatures*; at 817° precisely one-half, and at 1000° two-thirds of the strength are taken away. By comparing the areas of the sections of fracture with the tenacity, it will be observed that the largest sections seem to afford the highest results; but as several bars, in which the difference is more observable, are from different sheets of copper, we may reasonably suppose that a real difference in the quality of the article may have existed. This table has furnished the basis of the curve of tenacity accompanying this part of the report.

By applying the law above stated* and assuming the greatest diminution observed, or that obtained at 1000° above the freezing point, as a true standard of comparison, we get the calculated results contained in the 13th column of the table, and a comparison of that with the 12th, furnishes the *differences* in column 14th. This last, compared with the 9th, shows that the greatest deviations even of the anomalous experiments already noticed, do not amount to so much as the actual irregularities sometimes found in the metal at common temperatures, for while the highest numbers in the 14th column are less than four and one-tenth per cent. of the total strength, several of those in the 9th amount to more than four and a half per cent. of the same sum.

The curve traced, (Plate IX.) represents the column of calculated results, and is continued to the opposite side of the figure to show to what point this law would lead as the temperature of no tenacity.† This

* The following table exhibits the mean results of the several sets of comparisons with the *temperature above* 32°, at which each experiment was made, and the diminution of strength corresponding, agreeably to the preceding note.

TABLE XXV.

No. of the comparison.	Temperature above 32 degrees.	Diminution from the ascertained strength at 32 degrees.	Mean value of x, by 13 comparisons at each point.	Difference of each from the mean value of all the trials.
1	90.°	.0175	1.536	+.036
2	180.	.0540	1.462	—.038
3	270.	.0926	1.518	+.018
4	360.	.1513	1.444	—.056
5	450.	.2046	1.489	—.011
6	460.	.2133	1.474	—.026
7	513.	.2446	1.447	—.053
8	529.	.2558	1.466	—.034
9	660.	.3425	1.474	—.026
10	769.	.4398	1.570	+.070
11	812.	.4944	1.565	+.065
12	880.	.5581	1.542	+.042
13	984.	.6691	1.557	+.057
14	1000.	.6741	1.458	—.042
	Mean of 14 means=1.500=x			

Hence $t^{1.5} : t'^{1.5} :: d : d'$, or $t^3 : t'^3 :: d^2 : d'^2$, which is the practical rule above given.

† The application of the law deduced from the research in the preceding note, to the purpose of getting the column of calculated diminutions, as well as to that of extending the curve to the limit of tenacity, requires but a transformation of the proportion $t^3 : t'^3 :: d^2 : d'^2$ into the equation $\overline{\frac{t'}{t}}\Big|^3 = \overline{\frac{d'}{d}}\Big|^2$, whence $\overline{\frac{t'}{t}}\Big|^{\frac{3}{2}} = \frac{d'}{d}$, and $d' = d \times \overline{\frac{t'}{t}}\Big|^{\frac{3}{2}}$.

or $\frac{3}{2}(Log\, t' — Log\, t) + Log\, d = Log\, d'$. Thus to obtain the strength of copper at

is seen to be 1333 degrees Fah. which is 663 degrees lower than any determination of the melting point of copper hitherto made. It is well known that metals in general pass, in coming to the state of fusion, through a condition, in which though disintegration is nearly or quite complete, fluidity is not fully established; and in this granular state they, in some cases, continue through a considerable range of temperature. The melting points are those at which fluidity is clearly established. But notwithstanding this fact, and the very close accordance of the law above mentioned, with the observed diminutions of tenacity, we do not venture to assert that the theoretical law which might be derived from operating on copper absolutely pure, and of uniform tenacity throughout the specimen, would not give a form so varied as to change the parabolic curve into one possessing a *point of inflection.* An inspection of the figure as well as a reference to the table in the preceding note, will be found to favour the supposition that the rate of increase in temperature corresponding to a given decrease of tenacity, does in fact pass through a minimum near the point where one-half of the absolute tenacity is overcome. The right hand branch of the curve indicates the probable course *after inflection.*

Extensibility of Copper.

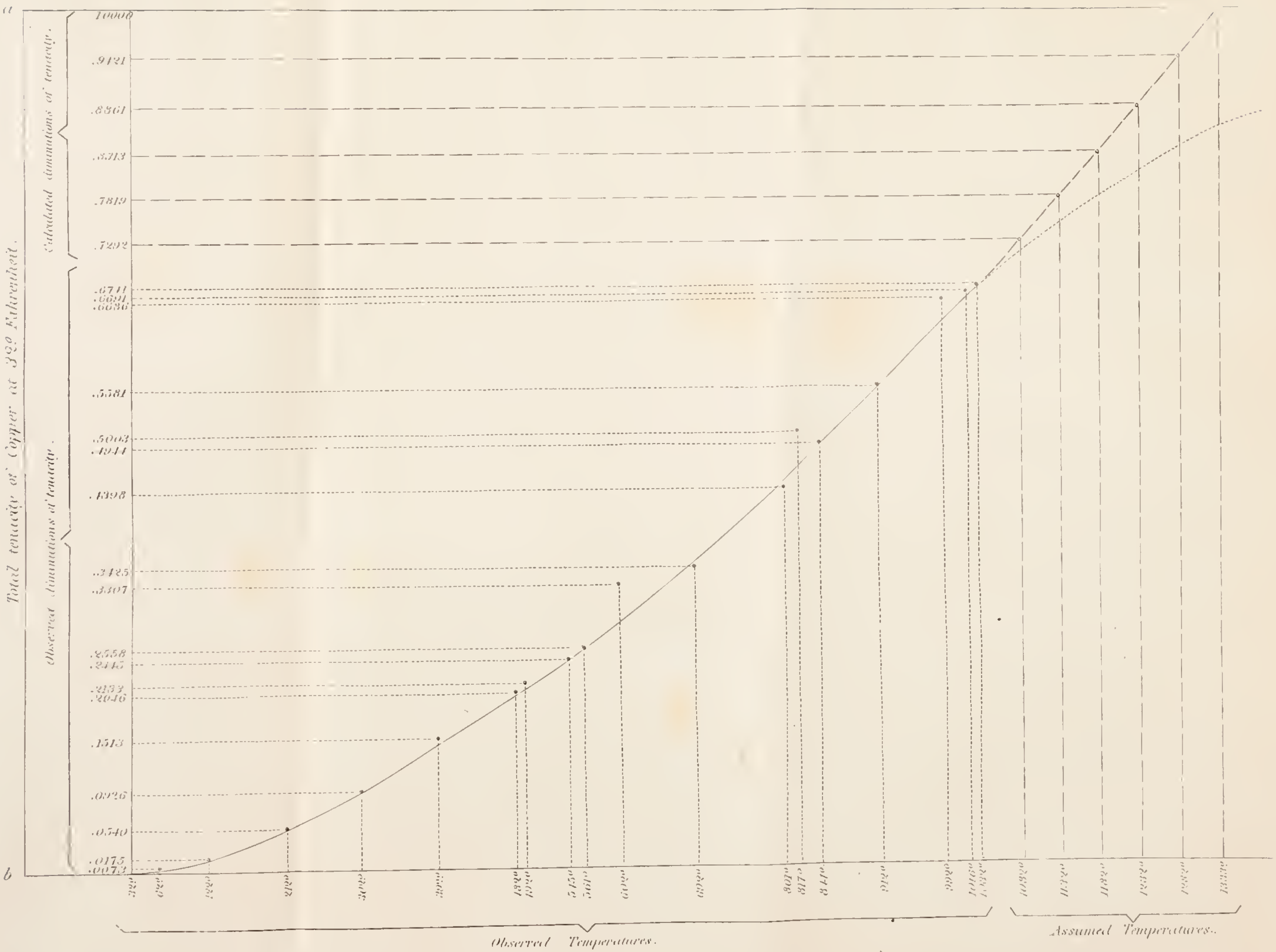
In producing the rupture of bars of copper it became evident that this metal undergoes during the mechanical strain to which it is subjected, a degree of elongation dependent, in some measure on the temperature to which it is raised. The mode of ascertaining this point, consisted in measuring after the trial of each bar had been completed, the united lengths of all its fragments. In reconstructing the bars for this purpose, care was taken to bring the corresponding portions into as close a contact as possible, and also to allow by estimation for any imperfection in the same from roughness of the fracture. A second mode was, to select from among the fragments of each bar one or more which retained the original inch-marks, and which had at the same time, been apparently strained to the full extent of its resistance, without actually parting. By this latter method of trial it was ascertained that the extensibility of all the 8 bars with the exception of Nos. 6 and 7, was nearly uniform, varying only between 40 and 44 per cent. of the original length. A section measured on No. 6, gave the length between two inch-marks only 1.25 inch, and on No. 7, 1.28. The trials on both these sections had been made at ordinary temperatures. When comparing the total lengths after fracture with the original length of each bar, we obtained as a general result, very nearly the same extension as when employing the several inch-marks as just stated. The mean elongation of the whole after 116

1232° Fah., we have $1232° - 32° = 1200°$ ∴ *Log* 1200=3.0791821

$$\begin{array}{rr}
Log\ 1200 = & 3.0791821 \\
Log\ 1000 = & 3. \\
\hline
 & .0791821 \\
 & 3 \\
\hline
 & 2)2375463 \\
\hline
 & .1187731 \\
\text{Add } Log\ .6741 = & -1.8287243 \\
\hline
\text{Gives } Log\ .8861 = & -1.9474964
\end{array}$$

Hence 1.000—.8861=.1139 is the *remaining strength;* or $11\frac{4}{10}$ per cent of the strength at 32°, is all that remains at 1232°, which is a visibly red heat in day light.

Plate IV


Total tenacity of Copper at 32° Fahrenheit.
Calculated diminutions of tenacity.
Observed diminutions of tenacity.
.9121
.8361
.7819
.7292
.6711
.6691
.6636
.5581
.5063
.4944
.4398
.3425
.3307
.2558
.2445
.2133
.2046
.1513
.0926
.0540
.0175
.0073
Observed Temperatures.
Assumed Temperatures.

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fractures, was 43.5 per cent. of the original length. Other things being equal, the bars of least area appeared to have been most extensible. No. 2 was stretched, by 18 fractures, from 30 to $46\frac{1}{4}$ inches. No. 8, by 14 fractures, from 30 to 43 inches. But the circumstance of most importance is the temperature of the bar at the moment of trial. Thus on bar No. 7, (Table XXII.) the first fracture was made at 912° and the area of section afterwards was $.744 \times .244 = .181536$ square inch, and the diminution from its original size only .002571, while at the thirteenth fracture, when the temperature was 81.5°, the area, after trial, was $.550 \times .174 = .095700$, a diminution of .088316, or 34 times as much elongation as before.

Strength of boiler-iron at ordinary temperatures.

The results of experiments on boiler-iron, at ordinary temperatures, will be found included in thirty-two tables, from XXVI. to LVII., inclusive. On some few of the specimens, the strength of which is exhibited in these tables, all the experiments were made with a particular view to the irregularities of the metal, and at, or near the same temperature, while on other bars much diversity in the objects of the experiments prevailed, and consequently of these, only a few trials can be selected which may be considered entirely appropriate to the present topic. When making comparisons with a view to the mean strength of sheet iron, even from the same plate, it is necessary to consider that the question may be answered differently according to the direction in which the specimen was cut off; to the condition in which it was submitted to trial, whether rough from the shears, filed to a uniform size, and smooth surface, or filed away in notches to overcome the influence of the shears; or finally, according to the previous treatment of the specimens, whether subjected or not to annealing or other influences of heat after leaving the rolls. The tables furnish, under appropriate heads, the information necessary to answer, separately, the several questions arising out of these different aspects of the subject. With regard to the method of preparing the specimens, by reducing them to an uniform size throughout the whole extent of the bar, it may be remarked, that on the forty-one bars of iron, which in the course of this report, are described as having undergone that preparation, there were measured 1049 points, or sections, and there were made 517 fractures, showing, on an average, but little more than two inches between two adjacent points of fracture. It also appears that on only two of those bars (Nos. 220 A. and 224 B.) did the mean area of all the points measured, correspond exactly with that of all the sections of fracture. On 22 bars the mean area of the fractured parts is *less* than that of the measured sections, by an average of .000340 of a square inch, and on 17 bars the mean section of fracture is *greater* than the mean measured sections by an average amount of .000187. This proves, what might indeed have been anticipated, that the fractures would, in general, take place at the smaller sections, and as the mean area was about .175 sq. inch, it appears that the difference between the measured and the fractured sections, due solely to irregularities of filing, that is, between the condition of our specimens and that of others which should be absolutely uniform in size, amounts to not more than $\frac{105}{175000}$ or $\frac{1}{1666}$ part of the total strength. This portion is less than the irregularities in the structure of rolled iron, as may be shown by referring to tables LV. and LVII.

TABLE XXVI.

Experiments on iron bars No. 2, 4, 6 and 8. Manufactured by Messrs. Mason, Miltenberger & Co., at the Pennsylvania Iron Works, Pittsburg, from Juniata piled *iron. Nos. 2 and 4, cut lengthwise of the*

Number of the bar.	Direction of the slit.	Number of the experiment.	DATE.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight X leverage.	Friction.
			1832.				sq. inch.		lbs.		
2	Length.	1	June 13.	23.55	.890	.260	.231400	60°	479	14370	718
2	"	2	"		.660	.258	.170280	79.5	378	11340	567
4	Length.	1	"	23.6	.980	.256	.250880	65	415	12450	622
4	"	2	"	13.2	1.030	.260	.267800	65	460	13800	690
4	"	3	"		.990	.260	.257400	65	493	14790	739
6	Cross.	1	"	21.25	1.000	.220	.220000	65	444.5	13335	666
6	"	2	"	19.	1.058	.254	.268732	65	493	14790	739
6	"	3	"	10.4	1.054	.260	.274040	65	526	15780	789
8	Cross.	1	"	21.2	1.000	.252	.252000	65	443	13290	664

TABLE XXVI.

sheet, and 6 and 8 crosswise of the same. With the exception of experiment No. 2, the trials were all made at original sections. Specific gravity, 7.7169.

Effective strain.	Strength in pounds per square inch.	Weights producing temporary elongation.	Elasticity of the bar.	Length after trial.	Area of section after trial.	REMARKS.
lbs.						
13652	58997	280— 236— 392— 448— 474— 479—	"15 "16 "19 "25 "21.5 Broke.	23.8	.878×.240 =.210720	
10773	63266				.640×.230 =.147200	This fracture was made at a section deeply filed in the bar with square shoulders, perpendicular to the length of the bar.
11828	47146			23.85		
13110	48955	224— 336— 448— 460—	..35 ..38 .16 Broke.	13.33	.996×.220 =.219120	
14051	54588				.958×.226 =.216508	
12669	57587			21.75		
14051	52286			19.1	1.048×.232 =.243136	
14991	54704				1.050×.234 =.245700	
12626	50103	280— 336— 392— 430— 443—	.20 .22 .15 .15 Broke.	21.4	.990×.228 =.225720	

TABLE XXVII.

Experiments on bar No. 3. Manufactured at the Pennsylvania Iron Works, by Messrs. Mason, Miltenberger, & Co., at Pittsburg, from Juniata piled iron—rolled into ¼ inch boiler-plate; cut with the shears

Marks.	Breadth.	Thickness.	Area before trial at the points measured.	DATE.	No. of the experiment.	Area of the section of fracture before trial.	Temperature. Fah.	Breaking weight in the scale.	Breaking weight multiplied by leverage.
				1834.					
1.	.757	.242	.183194	Jan. 13.	1	.183194	78°	346	10380
2.	.757	.242	.183194						
3.	.757	.243	.183951	"	2	.182979	78	354	10620
4.	.757	.243	.183951						
5.	.757	.243	.183951	Jan. 18.	3	.183194	520	356	10680
6.	.759	.241	.182919						
7.	.760	.241	.183160	"	4	.184437	572	371	11130
8.	.758	.243	.184194						
9.	.756	.243	.183708	"	5	.183951	574	379	11370
10.	.759	.242	.182678						
11.	.656	.242	.182952	"	6	.185074	576	399	11970
12.	.754	.242	.182468						
13.	.757	.244	.184708	"	7	.183951	76	417	12510
14.	.757	.243	.133951						
15.	.757	.242	.183194	"	8	.183160	76	417	12510
16.	.757	.243	.183951						
17.	.759	.244	.185196	"	9	.183194	76	417	12510
18.	.758	.244	.184952						
19.	.759	.243	.184337	"	10	.183708	76	417	12510
20.	.758	.243	.184194						
20.5	.753	.243	.182979	"	11	.183043	76	440	13200
Mean of 14=			.183751	"	12	.183951	76	440	13200
Maximum			.185196	"	Mean of 12	.183653			
Minimum			.182468						
Mean of the two			.183832						
Diff. of the two			.002628						

TABLE XXVII.

lengthwise of the sheet, and reduced by filing through 20.5 *inches of its length. Specific gravity* 7.7169.

Friction.	Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
519	9861	53828	No. 1.	
531	10089	55137	" 20½.	
534	10146	55389	" 2.	Part in melted tin from 9 to 13—the fracture is 7 inches from the melted metal.
556	10574	57331	" 19.	Six inches from the heated part.
568	10802	58722	" 3.	Six inches from the heated part.
598	11372	61445	" 17½.	Four and a half inches from the tin.
625	11885	64609	" 16.	
625	11885	64889	" 7.	
625	11885	64876	" 15.	
625	11885	64695	" 9.	
660	12140	68509	" 10⅞.	
660	12540	68170	" 14.	The mean area of the sections of fracture is .000098 sq. in. *less* than the mean area of the measured sections.

TABLE XXVIII.

Experiments on bars Nos. 9, 10, *and* 11. *Manufactured by Henry S. Spang & Son, at the Ætna rolling mill, near Pittsburg, Pa. The blooms made by Henry S. Spang, Huntingdon county, Pa. Hammered into slabs, and rolled into sheets. These bars, cut with the shears lengthwise of the sheet. The fractures, made either at original*

No. of the bar.	Direction of the slit.	No. of the Exp't.	DATE.	Length before trial.	Breadth before trial.	Thickness before trial	Area before trial.	Temperature. Fah.	Breaking weight in the scale.	Breaking weight multiplied by leverage.	Friction.
9	Length.	1	1832. Sep. 19,	23.7	1.000	.202	.202000	65.°	373.5	11205	+560*
9	"	2	"		.966	.210	.202860	65.	417.	12510	—625
9	"	3	"		1.000	.210	.210000	65.	427.	12810	—640
9	"	4	Sep. 26,		.691	.212	.146280	568.	394.	11820	—591
9	"	5	Oct. 3,		.596	.212	.126352	61.	289.	8670	—433
9	"	6	"		.734	.212	.155608	80.	378.	11340	—567
10	Length.	1	1832. Sep. 19,		.712	.204	.145248	575.	327.	9810	—490
10	"	2	"		.643	.204	.131172	100.	333.	9990	—499
10	"	3	Sep. 22,		.693	.204	.141372	73.	320.	9600	—480
10	"	4	"		.650	.201	.130650	574.	294.	8820	—441
10	"	5	"		.661	.208	.137488	571.	358.	10740	—537
11	Length.	1	1832. June 7.	23.6	1.000	.204	.204000	70.75	272.	8160	+408
11	"	2	"	18.6	.972	.201	.195372	70.75	348.	10440	—522
11	"	3	"		.954	.205	.195570	70.75	381.	11430	—571

TABLE XXVIII.

sections as the bar came from the shears, or at sections deeply filed on the edges with a semicylindrical file making two notches directly opposite to each other; between the deepest parts of which the measurements were taken. Specific gravity 7.7874.

Effective strain.	Strength in lbs. per square inch.	Length after fracture.	Area of the section after fracture.	REMARKS.
11765	58191	24.5	.932×.190 =.177080	* The bar was broken with a rising motion of the lever, that is, by drawing up the weight with the screw—hence the *friction* (.05 of the weight) is to be *added*.
11885	58587			Broke at an original section near the wedges.
12170	57952			Broke at an original section near the filed section, which now bore 59.462 lbs. per sq. in., its area being .997×.210=.205170.
11229	76763			This experiment made with great care, continued one and a half hours.
8237	65191			
10773	69232			
9320	64166			Broke suddenly at the filed section.
9491	72355			The temperature recorded is approximate only, being derived from the heated heads, still warm from the last experiment.
9120	64511			
8379	64133			
10203	74210			
8569	42000	23.9		Fracture made with a rising motion of the lever, the friction is therefore to be added to the weight.
9818	50253		.967×.167 =.161489	A section had been filed, the area of which was .193570, but the bar did not break at that point.
10859	55529		.870×.161 =.140070	Broke at the filed section above mentioned.

TABLE XXIX.

Experiments on bar No. 14, cut from a sheet of boiler iron by a cross section. Manufactured at the Ætna Rolling Mill, near Pittsburg, by Henry S. Spang & Son from blooms made by Henry S. Spang, in

Marks.	Breadth.	Thickness.	Area of section at the points measured.	DATE.	No. of experiment.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.
0	.698	.221	.154258					
1	.700	.210	.147000					
2	.700	.214	.149800	1833.	1	.157854	77	291
3	.695	.215	.149425	Oct. 25				
4	.697	.218	.151946					
5	.697	.216	.150552					
6	.697	.212	.147764					
7	.697	.215	.149855	"	2	.155400	732	291
8	.696	.221	.153816					
9	.695	.221	.153595					
10	.695	.221	.153595					
11	.697	.221	.154037	"	3	.148287	552	291
12	.697	.228	.158916					
13	.700	.225	.157400					
14	.700	.221	.154700					
15	.701	.224	.157024	Oct. 30.	4	.160310	59	343
16	.700	.224	.156800					
17	.700	.222	.155400					
18	.700	.228	.159600					
19	.700	.232	.162400	"	5	.155400	59	322
20	.700	.232	.162400					
21	.697	.230	.160310					
22	.692	.229	.158468					
				Nov. 7.	6	.150055	63	331
Mean of 23 =			.154746					
Maximum			.162400					
Minimum			.147000	"	7	.156476	64	340
Mean of the two			.154700					
Difference			.015400	"	8	.153705	64	342
					Mean of 8=	.154686		

TABLE XXIX.

Huntingdon County, Pa. Hammered *into slabs, and* rolled *into sheets. Specific gravity of the specimen from which it was cut*, 7.7874.

Breaking weight × leverage.	Friction.	Effective strain.	Breaking weight in lbs. per square inch.	Point of fracture.	REMARKS.
8730	436	8294	52542	No. $12\frac{3}{4}$	Part in tin from $15\frac{1}{2}$ to 18.
8730	436	8294	53378	" 17	
8730	436	8294	55932	" $6\frac{1}{4}$	
10290	514	9776	60982	" 21	
9660	483	9177	59054	" $13\frac{3}{4}$	
9930	496	9434	62870	" $3\frac{1}{4}$	
10200	510	9690	61926	" $11\frac{1}{2}$	
10260	513	9747	63413	" $8\frac{1}{2}$	The point of fracture had been crushed in the wedges in a former experiment. The mean of the 23 measurements taken before trial is *greater* than the mean of the 8 points of fracture by .000060 square inch.

TABLE XXX.

Experiments on bars Nos. 17, 18. 21, 22 *and* 23. *Manufactured by Messrs. H. S. Spang & Son, at the into slabs, and rolled. Specific gravity,* 7.77.

No. of the bar.	Direction of the slitting.	No. of the exp't.	DATE.	Length before trial.	Breadth.	Thickness.	Area of section before trial.	Temp. Fah.	Br. weight in the scale.	Br. weight × leverage.	Friction.	Effective strain.	Strength in lbs. per sq. inch.
17	Cross.	1	1832. April 4,	23.9	1.024	.260	.266240	59.°	374	11220	+561	11781	44249
18	Cross.	2	"		.986	.264	.260304	59.	415	12450	+622	13072	50218
21	L'gth.	3	"	24.1	.984	.252	.247968	69.	336	10080	504	9576	38618
21	"	4	"	17.4	.986	.260	.256360	69.	356	10680	534	10146	39578
22	L'gth.	5	Sept. 29.		.703	.249	.175047	565.	350	10500	525	9975	56984
22	"	6	Oct. 3.		.720	.257	.185040	581.	430	12900	645	12255	66229
22	"	7	"		.626	.255	.159630	90.	260	7980	399	7581	47491
22	"	8	Oct. 10.		.683	.255	.174165	68.25	354	10620	531	10089	57928
22	"	9	"		.687	.257	.176559	515.	383	11490	574	10916	61826
22	"	10	Oct. 25.		.627	.257	.161139	56.5	315	9450	472	8978	55716
22	"	11	Oct. 31.		.675	.260	.175500	90.	347	10410	520	9890	56353
23	L'gth.	12	Oct. 31.	24.3	1.004	.260	.261040	69.	392	11760	588	11172	42798
23	"	13	"	21.1	1.020	.260	.265200	69.	426	12780	639	12141	45780
23	"	14	Nov. 18.		.736	.264	.194304	394.5	462	13860	693	13167	67765
23	"	15	"		.775	.252	.195300	87.5	452	13560	678	12882	65960
23	"	16	"		.713	.256	.182528	87.5	380	11400	570	10830	59333

TABLE XXX.

Ætna Works, near Pittsburg, from blooms made by H. S. Spang, of Huntingdon county. Hammered

Wt. producing temporary elongation.	Elasticity of the bar.	Length after fracture.	Area of the section after fracture.	REMARKS.
259 280 294 326 336 350 364 371 374	23.′ 22. 14. 17.5 21. 24. 31.5 27. Broke.	24.1		Broke with a rising motion which makes the friction conspire with the weight in producing the fracture. Hence the sign + in the column of friction.
392 403 412 415 415 Elas.af. par.fr. 130— 214— 277	32. 37.5 39. 26· B.p't'ly off. 14. 18.5 Fin.br.off.		.980×.256 =.250880	After the bar had been for some time strained with 415 lbs., the process was arrested for the purpose of trying the elasticity under less weight. The remaining strength, it appears, was 277 lbs. $=\frac{277}{415}=\frac{9}{14}$ nearly; or about 64 per cent. of the original strength.
224—	17.	24.4	.966×.236 =.227976	The bar broke at once, on applying by mistake, 336 lbs. It is probable that this point was extremely weak'd by the shears, or by straightening it, after being cut.
280 321 336 356	25. 26. 28. Broke.	17.8	.970×.240 =.232800	Broke with a slow and regular application of weights.
				Do. This and the 6 following experiments were made on deeply filed sections.
				The fracture took place soon after adding the weight recorded. The experiment is, however, considered a fair one.
280 364 393	21. 31. Broke.	24.4	1.004×.240 =.240960	A flaw appeared in the edge, but before the final separation 8 or 9 pounds more *were necessary.*—Original section.
280 364 413 426	29. 22. ? 57. Broke.	21.45	.996×.254 =.252984	Broke at a section not filed.
			.660×.216 =.142560	Filed section.
				Do.
				Do.

TABLE XXXI.

Experiments on bar No. 16 boiler plate. Manufactured by Henry S. Spang & Son, at the Ætna Rolling Mill, near Pittsburg, Penn. The blooms made by Henry S. Spang, Huntingdon County, Pa. Ham-

Marks.	Breadth before trial.	Thickness before trial.	Area of sections at the points measured.
0	.750	.212	.159000
1	.747	.212	.158364
2	.738	.210	.154980
3	.742	.202	.149884
4	.744	.202	.150288
5	.750	.202	.151500
6	.750	.202	.151500
7	.749	.206	.154294
8	.749	.203	.152047
9	.747	.200	.149400
10	.747	.197	.147159
11	.747	.197	.147159
12	.747	.189	.141183
13	.746	.188	.140248
14	.746	.187	.139502
15	.750	.184	.138000
16	.750	.184	.138000
17	.750	.183	.137250
18	.750	.183	.137250
19	.751	.190	.142690
20	.750	.191	.143250
21	.750	.194	.145500
22	.750	.188	.141000
Mean of 23			.146497
Maximum			.159000
Minimum			.137250
Mn. of the 2			.148125
Diff. of the 2			.021805

The mean area of the 23 measured sections is .001697 sq. inch *greater* than that of the 11 sections of fracture.

No. of the Experiment.	DATE.	Area of the section of fracture.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight × leverage.
1	1833. Oct. 19.	.139999	57.5°	263	7890
2	"	.151500	636	266	7980
3	"	.154294	58	308	9240
4	"	.147159	58	323	9690
5	"	.150086	60	323	9690
6	Oct. 24.	.137250	766	264	7920
7	Oct. 26.	.137250	644	264	7920
8	"	.153281	72	338	10140
9	"	.138000	72	322	9660
10	"	.140877	72	304	9120
11	"	.143110	72	306	9180
	Mean	.144800			

	Br.	Th.	Area of the section of fracture.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight × leverage.
Experiments on bar No. 13 from the same specimen as the above. Length before trial 23.45.	.884	.212	.187408	65	332	9960
	.880	.212	.186560	65	336	10080
Experiment on No. 15 of which the length was 24 inches.	.954	.212	.202248	65	356	10680

TABLE XXXI.

mered into slabs and then rolled into sheets. This bar was cut across *the direction in which the sheet passed the rolls; reduced by filing, and gauged at every inch, from* 0 *to* 22. *Specific gravity*, 7.7874.

Friction.	Effective strain.	Strength in pounds per square inch.	Wts. producing temporary elongation.	Elasticity.	Point fractured.	REMARKS.
394	7496	53543			No. 13½	Part in tin from 4 to 7. Fracture in the melted metal. In taking the temp., with the pyrometer, a few grains of tin accompanied the standard piece, but were afterwards taken out and found to weigh 24°, which being added to the observed deficiency gave 400 + 212 + 24 = 636°.
399	7581	50039			" 5⅔	
462	8778	56887			" 7	
484	9206	62558			" 10	
484	9206	61338			" 3½	Broke with the same weight as the preceding.
396	7524	54819			" 17¾	The part in melted metal from 16 1-2 to 19 1-2; after having tried the temp. as the bar was stretching, and obviously ready to break, removed the furnace and took out the tin, suspended the weight on it for two days, after which the breadth was taken at the narrowest part, and found to be .691 inch instead of .750 as at first.
396	7524	54819			" 17¾	Same part in as above. The heating was now repeated, but instead of allowing the furnace to continue fixed, it was lowered when the bar began to stretch until the motion was retarded and then again brought up till it was renewed, and so on two or three times, to avoid heating the standard piece higher than was absolutely necessary to break the bar.
507	9633	63852			" 2⅓	
483	9177	66500			" 16	
456	8664	61500			" 18⅔	Had been near the hottest part.
459	8721	60939			" 19¾	Blue from heat.
			280	0°..32′	Areas after fracture.	
498	9462	50488	310	0 ..29	.860×.194=.166840	Broke at a part annealed. The length after fracture was 23.8, showing very little extension.
504	9576	51329	332	0 ..31	.862×.18=.15516	Broke in two places 2 inches apart.
534	10146	50166	280 329	0°53′ 0 40	.946×.190=.179740	Broke at the filed section, but not at the smallest part, showing an evident want of uniformity in strength. Length after fracture, 24.5.

TABLE XXXII.

Experiments on bar No. 19. Manufactured by Henry S. Spang & Son, from blooms made by Henry S. Spang, Huntingdon county, Pa. Hammered into slabs, filed and rolled into plate. This strip was cut

Marks.	Breadth.	Thickness.	Area before trial.	DATE.	No. of the experim't.	Area of the section of fracture.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.
1	.760	.250	.190000	1833.					
2	.754	.251	.189254	June 22,	1	.189128	576°	326	9780
3	.757	.255	.193035						
4	.754	.252	.190008						
5	.756	.248	.187488						
6	.755	.249	.187995						
7	.754	.251	.189254	"	2	.190000	570	378	11340
8	.756	.250	.189000						
9	.753	.252	.189756						
10	.755	.250	.188750						
11	.754	.251	.189254						
12	.754	.253	.190762						
13	.756	.252	.190512	June 29,	3	.188750	77	290	8700
14	.758	.253	.191774						
15	.758	.252	.191016						
16	.756	.251	.189756						
17	.757	.246	.186222	"	4	.189567	77	296	8880
18	.756	.245	.185220						
19	.757	.248	.187736	"	5	.187995	77	305	9150
20	.753	.246	.185238						
21	.773	.244	.188612	"	6	.187488	77	315	9450
Mean of 21=			.189078	"	7	.189254	77	319	9570
Maximum			.193035	"	8	.190595	72	234	7020
Minimum			.185220						
				"	9	.185470	72	267	8010
Mean of the 2=			.190627						
Diff. of the 2=			.007815	"	10	.186478	72	291	8730
				"	11	.186487	73	314	9420
				"	12	.191774	73	290	8700
				"	13	.187989	73	291	8730
					Mean of 13 =	.188536			

TABLE XXXII.

with the shears in a direction crosswise of the sheet, reduced to a nearly uniform size by filing. *Specific gravity* 7.7764.

Friction.	Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
489	9291	49125	No. $10\frac{3}{4}$	In tin from $9\frac{1}{2}$ to 13. The bar, on being strained, manifested an unequal extensibility in the three different laminæ of which it was composed.
567	10773	56700	" 1	Part now in tin is from $2\frac{1}{2}$ to $6\frac{1}{2}$, the length of the part embraced between the two heads is 8 inches. On raising the temperature from 180° to 510°, under a strain of 326 lbs. the index fell 1° 05′ on the arc.
435	8265	43788	" 10	Broke at a part previously griped by the wedges. This and the subsequent trials were on annealed portions.
444	8436	44501	" $8\frac{3}{4}$	
457	8693	46187	" 6	
472	8978	47886	" 5	
478	9092	48041	" 2	
351	6669	34990	" $12\frac{2}{3}$	
400	7610	41031	" $17\frac{3}{4}$	
436	8294	44477	" $18\frac{1}{2}$	
471	8949	47987	" $19\frac{1}{2}$	
435	8265	43098	" 14	
436	8294	44120	" $16\frac{1}{2}$	The mean area of fracture is *less* by .000542 square inch than the mean area of the measured sections.

TABLE XXXIII.

Experiments on bars No. 25, 27, 30, 32, 35, 37, 39 *and* 41. *Manufactured at the Sligo Iron Works, Pittsburg, by Barnet Shorb, from Juniata blooms, piled and rolled into boiler-plate. Nos.* 25 *and* 27 *were cut lengthwise from a quarter-inch sheet, and Nos.* 30 *and* 32, *crosswise*

No. of the bar.	Direction of the slit.	DATE.	No. of the experim't.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
25	Length,		1	24.1	1.000	.238	.238000	69.°	370.	11100	555
25	"		2	19.2	1.022	.240	.245280	69.	378.	11340	567
25	"		3	17.4	1.072	.236	.252992	65.	410.	12300	615
25	"		4		1.093	.234	.255762	65.	413.	12390	619
25	"		5		1.080	.232	.250560	65.	416.	12480	624
25	"		6		1.107	.232	.256824	65.	439.	13170	658
27	Length,		7	24.2	1.012	.204	.206448	62.5	403.	12090	604
35	Length,		8	23.15	1.092	.214	.233688	59.	354.5	10635	531
37	Length.	1832. May 15,	9	22.	.480	.220	.105600	73.5	171.	5130	256
30	Cross,		10	22.9	.874	.240	.209760	62.5	329.	9870	493
32	Cross,		11	23.	1.060	.234	.248040	60.	410.	12300	+647
39	Cross,		12	23.5	1.040	.214	.222560	73.5	317.	9510	475
41	Cross,		13	23.35	.994	.222	.220668	73.5	292.	8760	438

TABLE XXXIII.

from the same. Nos. 35 and 37 were taken lengthwise, from a three-sixteenth inch-sheet; 39 and 41, crosswise from the same. The specific gravity of the first four was 7.764, and of the other four, 7.7954.

Effective strain.	Strength in lbs. per square inch.	Weight producing temporary elongation.	Elasticity of the bar.	Length after trial.	Area of section after fracture.	REMARKS.
10545	44307	224 361 370	39. 28.5 Broke.	24.4	.980×.210 =.205800	Broke at the smallest section.
10773	43921			19.9	.978×.214 =.209292	Broke at an unfiled section
11685	46186				1.014×.195 =.197730	Broke at an original section. A section had been filed to the area of 1.044×.234=.244296.
11771	46023				1.066×.203 =.216398	
11856	47319				1.060×.189 =.200340	
12512	48718				1.103×.196 =.216188	
11486	55636	224 336 392 403	35. 38. 53. Broke.	24.4	.986×.196 =.193256	Br. at an original section.
10104	43237			23.2	1.088×.204 =.221952	Br. at an original section—no filing on this bar.
4874	46155	112 162 171	33. 43. Broke.	22.1	.440×.202 =.088880	A narrow strip. Broke at an original section.
9377	44703			23.1		
12947	52197	112 168 224 280 336 392 410	10.5 10. 12. 13.5 16. 17. Broke.	23.1	1.044×.216 =.225504	Br. with a rising motion of the lever, that is, while taking up the weight by the force of the screw—the friction is therefore positive & one-nineteenth of the wt.
9035	40595	224 315 317	20. 31. Broke.	23.65	1.020×.204 =.208080	The lamellated structure was exhibited by the different port'ns in the thickness, having separated for more than 4 inches near the frac.
8322	37713	224 282 292	45. 27.5 Broke.	23.85	.948×.216 =.204768	This bar had been cut from the same specimen as the preceding and broke in the same manner, viz. with a flaky separation of the laminæ.

TABLE XXXIV.

Experiments on bars No. 42, 43, 44, 46 *and* 48. *Manufactured by H. Blake & Co., Pittsburg. The first three were made by puddling, from pigs obtained at the Kentucky Iron Works, Greenup co., Ky. The last two were rolled from Juniata blooms, previously hammered.*

No. of the specimen.	Direction in which it was cut from the sheet.	Mode of manufacture.	DATE.	No. of the experim't.	Length of the bar before trial.	Breadth of the section of fracture before trial.	Thickness before trial.	Area of the section before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
42	Length,	Puddled,	1832. May 12,	1	23.8	.970	.252	.244440	73.5°	443	13290	664
42	"	"		2	22.45	.980	.252	.246960	73.5	452	13560	678
42	"	"		3	18.8	.978	.252	.246456	73.5	462	13860	693
43	Length,	Puddled,	"	4	23.2	1.140	.250	.285000	73.5	441	13230	661
44	Length,	Puddled,	"	5	23.7	1.048	.254	.266192	73.5	503	15090	754
44	"	"	"	6	17.9	1.048	.248	.259904	73.5	507	15210	760
46	Length,	Hammered plate,	"	7	24.4	.624	.242	.151008	68.	314	9420	471
46	"	"	"	8	19.8	.624	.242	.151008	68.	324	9720	486
48	Length	Hammered plate,	1832. May 19,	9	24.5	.976	.246	.240096	73.	503	15090	754
48	"	"		10	21.9	1.010	.246	.248460	73.	518	15540	777

TABLE XXXIV.

into slabs, and constituting "hammered plate." *These strips were all cut lengthwise of the sheets from which they were taken. The specific gravity of* 42, 43 *and* 44, *was* 7.682 ; *that of* 46 *and* 48, *was* 7.6785.

Effective strain.	Strength in pounds per square inch.	Weights under which elasticities were taken.	Elasticity of the bar.	Length after trial.	Area of the section after fracture.	REMARKS.
12626	51653	224 336 399 427 443	27. 32. 28.5 31. Broke.	23.9	.960×.236 =.226560	This fracture exhibited, in some parts, a smooth steel-like appearance, and in others a resemblance to cast iron.
12882	52162	399 427 452	28.5 31. Broke.	22.55	.960×.236 =.226560	Broke at an original section.
13167	53425	399 462 462	28.5 22. Broke.	18.9	.970×.236 =.228920	Do.
12569	44102	441	25.	23.35	1.120×.236 =.264320	Do.
14336	53836	224 336 448 476 496 503	25. 25. 23. 36. 34. Broke.	24.1	1.010×.228 =.230280	Did not break at the smallest section.
14450	55597			18.0	1.036×.242 =.250712	The thickness at the point of fracture had probably been reduced by the former strain.
8949	59262	224 280 297 314	29. 29. 28.5 Broke.	24.8	.570×.210 =.119700	Broke at a section deeply filed.
9234	61149			20.1	.578×.206 =.119068	
14336	59710	224 336 425 444 464 478 487 503	16. 18. 21.5 30. 27. 31. 28. Broke.	25.2	.896×.194 =.173824	Broke at a filed section.
14763	59418			22.15	.968×.204 =.197473	Original section.

TABLE XXXV.

Experiments on bars No. 51, 53, 56, *and* 58. *Manufactured by Henry Blake & Co., of Pittsburg. Cut crosswise of the sheets from which they were taken, the first two* (51 *and* 53) *from a boiler-plate of*

No. of the bar.	Direction of the slit.	Mode of manufacture.	No. of the exp's.	DATE.	Length of the bar before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temp. Fah.	Breaking w't.	Breaking w't. × leverage.	Friction.
51	Cross.	Ham'ed.	1	1832. May 19.	24.	.874	.258	.225492	73	472	14160	708
"	"	"	2	"	21.5	.830	.258	.215140	73	472	14160	708
53	Cross.	Ham'ed.	3	"	24.	.972	.250	.243000	73	478	14340	717
"	"	"	4		21.	.956	.262	.250472	73	500	15000	750
56	Cross.	Puddled.	5		23.7	.918	.248	.227664	73	471	14130	706
"	"	"	6		20.3	.944	.258	.243552	73	495	14850	742
58	Cross.	Puddled.	7	May 26.	23.7	1.044	.244	.254736	62.5	452	13560	678
"	"	"	8	"	22.35	.986	.256	.252416	62.5	479	14370	718
"	"	"	9	"	20.7	1.002	.258	.258516	62.5	496	14880	744
"	"	"	10	June 30.		.738	.253	.186714	394	471	14130	706
"	"	"	11	"		.706	.246	.173676	81	448	13440	672
"	"	"	12	"		.696	.257	.178872	81	429	12870	643

TABLE XXXV.

of Juniata hammered, and the other two, from one of Kentucky puddled iron. The specific gravity of the former, 7.7567, *that of the latter,* 7.6511.

Effective strain.	Strength in lbs. per square inch.	Wts. producing temporary elongation.	Elasticity of the bar.	Length after fracture.	Area of section after fracture.	REMARKS.
13452	59656	224 336 448 464 472	53 53 27 32 Broke.	24.5	.828×.224 =.186472	
13452	62527			21.6	.800×.230 =.184000	Broke at the smallest section under the same weight which had broken the larger section in the first expt.
13623	56062	224 336 448 464 478	37 36 21 22 Broke.	24.45	.948×.224 =.212352	Did not break at the *filed* section.
14250	56892	494 500	25 Broke.	21.4	.916×.234 =.214344	do. do.
13424	58964	224 336 448 471	07 07 21 Broke.	23.83	.898×.234 =.210132	Two different sect's. had been filed, one near the middle, another near the end of the bar. The frac. now took place at the latter.
14108	57926	448 495	25 Broke.	20.35	.926×.244 =.225944	This section had been near the middle of the bar in the preceding trial. The fracture was not now made in the narrowest part of the filed section. The breadth of that part after the fracture was .906, its thickness .258. Calculating for the same breaking weight on the narrowest part the strength exhibited was 59604.
12882	50570	224 336 392 448 452	49 54 50 44 Broke.	23.8	1.030×.214 =.220420	Broke near the wedges.
13652	54085	448 479	26 Broke.	22.45	.980×.238 =.233240	This and the two preceding experiments were on sections not filed, the three following were on filed sections intended to indicate the degree of weakness produced by the shears.
14136	54681	479 496	57 Broke.	20.8	.978×.234 =.228852	
13424	71896				.715×.224 =.160160	Broke suddenly in hot oil.
12768	73516				The mean area by 10 trials is 87.8 per ct. of the areas of the same sections before trial.	The weight was raised from the floor by the screw, and subsequently taken up by the windlass still higher, but on letting it down again the bar broke. Result doubtful.
12227	68356					Broke short at the filed section but not so suddenly as in the 10th expt.

TABLE XXXVI.

Experiments on bars No. 59, 60, 61 *and* 62. *Manufactured by H. Blake & Co., Pittsburg, by puddling and rolling into boiler-plate. The pigs obtained from the Kentucky Iron Works, Greenup county, Ky.*

No. of the bar.	Direction of the slit.	DATE.	No. of the exp't.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temperature. Fahrenheit.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
59	Length,	1832. May 23,	1	23.51	.906	.168	.152208	66.°	258	7740	387	7353
60	Length,	Nov. 22,	2	23.55	.550	.170	.093500	59.75	200	6000	300	5700
60	"	"	3		.550	.170	.093500	567.5	240	7200	360	6840
60	"	Nov. 24,	4		.545	.172	.093740	54.	193	5790	289	5501
60	"	"	5		.523	.171	.089433	558.	226	6780	339	6441
60	"	"	6		.569	.175	.099575	61.5	212	6360	318	6042
60	"	"	7		.527	.168	.088536	61.5	191	5730	286	5444
61	Length,	May 23,	8	23.6	1.048	.182	.190736	66.	336	10080	504	9576
61	"	June 27,	9		1.030	.184	.189520	82.	364	10920	546	10374
61	"	"	10		1.057	.178	.188146	394.	349	10470	523	9947
61	"	"	11		1.051	.179	.188129	82.	378	11340	567	10773
61	"	"	12		1.020	.172	.175440	82.	378	11340	567	10773
61	"	"	13		.945	.170	.160650	394.	349+	10470	523	9947
62	Length,	July 18,	14		.697	.184	.128248	580.	315	9450	472	8978
62	"	"	15		.683	.186	.127038	570.	298	8940	447	8493
62	"	"	16		.722	.177	.127794	574.	329	9870	493	9377
62	"	"	17		.700	.177	.123900	82.	278	8340	417	7923
62	"	"	18		.676	.182	.123032	82.	252	7560	378	7182
62	"	"	19		.680	.180	.122400	82.	261	7830	391	7239
62	"	"	20		.727	.181	.131587	82.	266	7980	399	7581

TABLE XXXVI.

A part of the experiments made upon original sections, others on filed sections, in which nearly one-half of the original breadth of the bar was taken away. Specific gravity 7.6013.

Strength in lbs. per square inch.	Weight producing temporary elongation.	Elasticity of the bar.	Length after fracture.	Area of section after trial.	REMARKS.
48308	112 168 224 242 258	12.5′ 20. 27. 27. Broke.	23.7	.888×.152 =.135376	Broke at a section not filed, in the middle of the bar.
60963					Began with a filed section near one end of the bar.
73155					This section was about seven inches from the preceding.
58684					This section is the part between the two preceding.
72021					Temp. had been as high as 572°; having lowered the lamp, it fell at the moment of fracture to the point noted.
60678					Filed section as above.
61489					Do.
50211	224 280 326 332 336	40. 42. 38. 36. Broke.	23.65	1.024×.166 =.169984	A section had been filed in the bar, which appears not to have been deep enough, as it did not break there. The *elasticities* were repeatedly taken under each weight, and are considered very accurate.
54738					Broke at once under the weight noted. The bar had now a filed section of .945×.170=.160650.
52869					Broke out of the filed section—which was the same as in the preceding experiment.
57264					
61405					The strength of the filed section must be *above* 10773÷.16065=67058 lbs., for that section was *not broken*.
61917					This calculation shows how much per sq. inch was borne by the filed section in experiment tenth.
70005					
66854					
73385					
63947					
58375					Broke immediately on applying the weight noted in the table.
59142					
57612					

TABLE XXXVII.

Experiments on bars No. 64, 65, 68, 70, 71 and 73. Manufactured by H. Blake & Co. of Pittsburg. The first two made by the process of puddling—the pigs obtained from Greenup county, Kentucky; the other four hammered into slabs from Juniata blooms, and then rolled into boiler-plate. The fractures

No. of the bar.	Direction of the slit.	Mode of manufacture.	DATE.	No. of the exp.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temp. Fah.	Br. weight in the scale.	Br. weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.
68	Length,	Hammered plate.	1833. Jan. 5.	1	24.0	1.096	.202	.221392	62°.5	450	13500	675	12825	57929
68	"	"		2	20.8	1.008	.200	.201600	62.5	455	13650	682	12968	64325
70	Length,	Hammered plate,		3	23.9	1.054	.214	.225556	65.	377	11310	565	10745	47638
64	Cross,	Puddled,		4	24.2	1.018	.208	.211744	73.	335	10050	502	9548	45092
65	Cross,	Puddled,		5	24.25	1.012	.200	.202400	65.	364	10920	546	10374	51255
65	"	"	Ja. 12.	6		.580	.189	.109620	46.5	242	7260	363	6897	62917
71	Cross,	Ham'red plate,		7	24.1	1.024	.164	.167936	62.5	357	10710	535	9175	54634
71	"	"		8	23.1	1.032	.170	.175440	62.5	414	12420	621	11799	67254
71	"	"		9		1.034	.170	.175780	62.5	440	13200	660	12540	71338
71	"			10		1.066	.182	.194012	62.5	459	13770	688	13082	67429
71	"	"		11		1.004	.208	.208832	62.5	465	13950	697	13253	63462
73	Cross,	Hammered Plate,		12	23.95	1.006	.184	.185104	73.	342	10260	513	9747	52657

TABLE XXXVII.

with the exception of the second on bar No. 65, (exp't. 6 of the table,) were made at original sections, left by the shears. Specific gravity of 64 and 65.=7.6511; and that of 68, 70, 71 and 73=7.79.

Weight producing temporary elongat'n.	Elasticity of the bar.	Length after trial.	Area of the section after trial.	REMARKS.
224 336 392 414 441 450	32.′ 31. 28. 30. 32. Broke.	24.45	1.040×.166 =.172640	Broke at an original section.
224 448 455	32. 20. Broke.	20.9	.952×.188 =.178976	Do.
112 224 280 336 364 377	19.5 16. 19. 23. 26. Broke.	24.05	1.008×.192 =.193536	Original section—Broke with the rising motion of the lever while taking up the screw. The friction is therefore to be added. Under a strain of 280, measured a certain portion and found it 16.7 inches long; under 336 lbs. it was 16.9; under 364 lbs. 17.05, and with 377, 17.1 inches. Extension 17.10—16.7=.4 in. or 2.4 per cent.
112 224 280 301 329 336	38. 55. 51.5 52.5 46. Broke.	24.3	1.014×.202 =.204828	Original section.
224 280 336 364	19. 18. 27. Broke.	24.3	1.012×.188 =.190256	Original section.—A portion of this bar, 17.85 inches long when under a strain of 336 lbs., was found to be only 17.817 when the strain was off, recoil .033=1—540th of the whole length. This was a deeply filed section made for the purpose of ascertaining the weakening effect of the shears.
224 336 357	20. 27. Broke.	24.22	.986×.130 =.128180	Broke at an unfiled section at the gripe of the wedges.
336 392 414	28. 26. Broke.		1.012×.126 =.127512	Broke again at an unfiled section.
			1.012×.136 =.137632	Do.
			1.056×.156 =.164136	Do. After this exp't. the bar, which had at first been 24.1 inches long, was found to be 25.3;—gain one and two-tenths by 5 fractures.
112 224 280 308 322 336 342	05.5 11. 18. 19.5 33. 24. Broke.		.960×.160 =.153600	Broke at an unfiled section.

TABLE XXXVIII.

Experiments on bar No. 49. Manufactured from Juniata blooms, hammered into boiler plate, by Messrs. H. Blake & Co., of Pittsburg,

Marks.	Breadth.	Thickness.	Area before trial.	Marks.	Breadth after trial.	Thickness after trial.	Area after trial.
				Measures after 1st fracture.			
0	.745	.205	.150675	0	.731	.200	.146200
1	.744	.206	.153264	1	.724	.201	.145524
2	.745	.209	.155705	2	.726	.202	.146652
3	.745	.211	.157195	3	.735	.208	.152880
4	.747	.211	.157617	4	.732	.207	.151524
5	.747	.210	.156870	5	.738	.209	.154342
6	.747	.210	.156870	6	.739	.206	.152234
7	.748	.210	.157080	7	.740	.207	.153180
8	.748	.212	.158576	8	.736	.205	.150880
9	.748	.211	.157828	9	.730	.203	.148190
10	.746	.210	.156660	10	.726	.202	.146652
11	.744	.211	.156984	11	.718	.201	.144318
12	.744	.211	.156984	12	.719	.203	.145958
13	.745	.210	.156450	13 (Smallest section and place of first fracture.)	.675	.181	.122175
14	.747	.211	.157617	14	.728	.201	.146328
15	.748	.212	.157576	15	.734	.206	.151204
16	.745	.210	.156450	16	.732	.202	.147864
17	.746	.210	.156660	17	.726	.201	.145926
18	.747	.211	.157617	18	.722	.201	.145122
19	.742	.209	.155078	19	.726	.203	.147378
20	.744	.208	.154752	20	.718	.200	.143600
20.3	.739	.210	.155190	20.3	.728	.199	.144872

No. of the exp's.	Area of the section of fracture before trial.	Temp. Fah.	Breaking wht. in the scale.	Break. wht. X leverage.
1	.156450	65	316	9480
2	.156984	440	322	9660
3	.153264	574	335	10050
4	.156975	572	343	10290
5	.156822	65.75	361	10830
6	.156450	65.	369	11070
7	.157244	65.	369	11070
8	.157406	65.	377	11310
9	.154971	65.	337	10110
10	.156347	61.5	337	10110
11	.157138	61.5	337	10110
Mean of 11 =	.156368			
Mean of 22 orig. meas. =	.156359			
Max. of do. =	.158576			
Min. of do. =	.150675			
Mean of these two =	.154625			
Difference of the two =	.007901			

Measures taken after the 4th fracture with 343 pounds.

Marks.	Breadth.	Thickness.	Area.
0	.725	.195	.141375
1	.702	.195	.136890
2	.713	.197	.140461
3	.730	.206	.150380
4	.728	.204	.148512
5	.729	.204	.148716
6	.726	.206	.149556
7	.728	.202	.147056
8	.729	.202	.147258
9	.725	.200	.145000
10	.718	.200	.143600
11	.720	.200	.144000

TABLE XXXVIII.

{ *Pa. This strip was cut lengthwise of the sheet and then reduced to uniformity by filing. Specific gravity*, 7.6875.

Friction.	Effective strain.	Strength in lbs. per sq. inch.	DATE.	Wt. produ. elon. before fracture.	Effects of the weights applied.	Points fractured.	REMARKS.
			1832.	lbs.			
			Nov. 29.	238	{ no perm. elonga.		Began by trials to ascertain the commencement and progress of elongation.
				245	{ perman. elongat.		
				259	{ 20.3 had exten. .15 in.		The length on which measurements were taken was originally 20.3 inches.
				266	.20		
				273	.30		
				280	.36		After this strain was taken off the bar recoiled 1-20 inch in length.
				294	.38		
				301	.58		Taking this strain off it recoiled 6-100 inch.
				306	.95		On taking off this strain it recoiled 4-100 in.
				313	1.14		do. do. 4-100
				316	1.42		The bar of 20.3 inches now measured 21.72.
						No.	
474	9006	57565	Dec. 1.			13	Broke at the smallest section in the bar.
483	9177	58458	"			11½	Part in tin from 5 to 8 inclusive. Fracture very near the wedges.
502	9548	62798	Dec. 6.			1	Broke near the wedges; arrested the motion before the bar actually parted.
514	9776	62278	"			6½	Fracture in the tin short and sudden.
541	10289	65609	"			10½	Broke within the wedges.
553	10517	67223	"			2½	Had not been in tin.
553	10517	66883	"			9½	Had been near the tin.
565	10745	68263	"			3½	
505	9605	61919	"			20	A different piece from the preceding.
505	9605	61434	Dec. 8.			18½	
505	9605	61121	"			17½	Broke after some delay.
							The mean area of the sections fractured was .000009 square inch *greater* than the mean area of the measured points.
							The mean area of the 12 measured points from 0 to 11 was, before trial, .156277; after the first fracture, .149381; and after the fourth fracture, .145233. Hence the increase of length by a strain of 9006 lbs. was 4.4 per cent., and by 9776 lbs. it was 7 per cent.

TABLE XXXIX.

Experiments on bar No. 74. Manufactured by H. Blake & Co. Pittsburg, from Juniata blooms. Hammered and rolled, making what is termed hammered plate. *This, and numbers* 71, 72 *and* 73, *were from a strip, cut* across *the sheet. The specific gravity of these four bars was* }

Marks.	Breadth.	Thickness.	Area before trial.	Measures after the first frac.				DATE.	No. of the experiment.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.
				Marks.	Breadth after trial.	Thickness after trial.	Area of section after trial.					
0	.770	.174	.133980									
1	.760	.166	.126160	0	.766	.173	.132518	1833.				
2	.765	.165	.126225	1	.759	.165	.125235	Jan. 10,	1	.125895	59.5°	218
3	.762	.167	.127254	2	.763	.163	.125895					
4	.765	.167	.127755	3	.759	.167	.126753					
5	.764	.168	.128352	4	.757	.167	.126419	Jan. 12,	2	.119886	48.	224
6	.761	.168	.127848	5	.761	.165	.125565					
7	.761	.166	.126326	6	.758	.166	.125828					
8	.765	.165	.126225	7	.746	.160	.119360	"	3	.126442	48.	225
9	.765	.166	.126990	8	.750	.161	.120750					
10	.765	.165	.126225	9	.755	.162	.122310					
11	.765	.165	.126225	10	.748	.161	.120428	"	4	.126390	49.5	229
12	.759	.164	.124476	11	.736	.158	.116288					
13	.759	.165	.125235	12	.724	.154	.111596					
14	.763	.165	.125895	13	.725	.158	.114590	"	5	.126225	550.	224
15	.765	.166	.126990									
16	.766	.165	.126390	Mean of 14=			.124129					
17	.768	.164	.125952									
18	.768	.163	.125184	Mean of the same 14 sections before trial, .127991. Diminution .002962=2.3 per cent.								
19	.768	.163	.125184					"	6	.130070	564.	266
19.6	.754	.159	.119886									
Mean of 21			.125840					Jan. 19,	7	.126607	52.	280
Maximum			.128352									
Minimum			.119886					"	8	.126326	52.	291
Mn. of these 2			.124119									
								"	9	.126568	52.	295
Diff. of the 2			.008466									
								"	10	.127755	52.	295
								Mean of 10		.126216		

TABLE XXXIX.

found to be 7.7910. *The bar was two feet in length, of which a section* 19.6 *inches in length was filed and gauged, and two end sections, about* 1 *inch wide and* 2 *inches each in length, were left to be grasped by the wedges in the first trial.*

Breaking weight multiplied by leverage.	Friction.	Effective strain.	Strength in lbs. per sq. inch.	Point of fracture.	REMARKS.
6540	327	6213	49351	No. 14	Stretched very much before breaking.
6720	336	6384	53250	" 19.6	
6750	387	6363	50332	near $14\frac{1}{2}$	Point of frac. not precisely ascertained.
6870	343	6527	51641	" 16	
6720	336	6384	50576	" 11	Part in tin from 5 to 8 inclusive. Temp. had been as high as 640°. Broke near the wedges—as far as possible from hot part.
7980	399	7581	58284	" $0\frac{1}{2}$	Part in tin 4 to 7 incl. Fracture at the extremity of the parts included between the wedges, as far as possible from the hot part. Temperature had been as high as 602°.
8580	429	8151	64380	" $8\frac{1}{2}$	
8730	436	8294	65655	" 7	
8850	442	8408	66431	" $2\frac{1}{3}$	
8850	442	8408	65813	" 4	The mean area of the 10 sections of fracture is .000376 sq. inch *greater* than that of the 21 measured sections.

TABLE XL.

Experiments on bars No. 75, 78, 85, 86 *and* 87. *Manufactured at the Juniata Iron Works, near Pittsburg, by Messrs. Schoenberger & Son, from blooms, by hammering and rolling. These were all cut off*

Number of the bar.	Direction of the slit.	Number of the experiment.	DATE.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight X leverage.	Friction.	Effective strain.
85	Length.	1	1832. May 10,	24.5	1.040	.260	.270400	66	462	13860	693	13167
85	"	2		22.1	.990	.254	.251460	66	481	14430	721	13709
85	"	3			.928	.250	.232000	66	492	14760	738	14022
86	Length.	4			.675	.256	.172800	580	394	11820	591	11229
86	"	5			.687	.256	.175872	580	406	12180	609	11571
86	"	6			.677	.257	.173989	90	360	10800	540	10260
86	"	7			.678	.257	.174246	32	381	11430	571	10859
86	"	8			.715	.257	.183755	32	420	12600	630	11970
87	Length.	9		24.5	1.028	.256	.263168	66	464	13920	696	13224
87	"	10		19.	1.060	.260	.275600	66	506	15180	759	14421
75	Length.	11		24.6	.664	.182	.120848	67	262	7860	393	7467
75	"	12		21.4	.724	.184	.125976	66	267	8010	400	7610
75	"	13			.675	.184	.124200	396	272	8160	408	7752
75	"	14			.672	.188	.126336	86	262	7860	393	7467
78	Length.	15		24.4	1.028	.186	.191208	73	280	8400	420	7980
78	"	16			1.014	.186	.188604	73	293	8790	293	8351

TABLE XL.

lengthwise of the sheet and tried either at original or at detached filed sections. Specific gravity, 7.7580.

Strength in pounds per square inch.	Weight producing temporary elongation.	Elasticity of the bar.	Length after trial.	Area of section after trial.	REMARKS.
48694	112 224 336 392 420 448 462	11.5′ 15. 33. 38. 36. 24. Bro.		1.036×.240 =.248640	Broke at an unfiled section.
54518	224 336 392 462 481	15. 23. 24. 28. Bro.	22.25	.954×.240 =.228960	Broke at an unfiled section.
60440				.894×.218 =.194892	Broke at the filed section.
64983					
65791					
58969					
62360					
65141					
50249	224 336 392 441 464	21. 16. 25. 25. Bro.	24.7	1.028×.184 =.189888	A filed section had been made with an area of 1.012×.256=.259072, but the frac. took place at an unfiled sect. Two or three flaws were disclosed near the filed section.
52326				1.050×.234 =.245700	The filed sect. in this exp. had an area of .270920=1.042×.260.
61788	257 262	8. Bro.	24.7	.650×.160 =.105000	A short piece only, embraced between the heads.
60408	168 267	10. Bro.			
62415					Broke outside of oil, near wedges.
59104					Broke at the filed section.
41734	112 224 280 280	14.5 17.5 21. Bro.	24.52	1.004×.160 =.160640	A part of this bar, 15.5 in. long, had become 15.55, under a strain of 280 lbs., but without the tension it was 15.525. Stretched rapidly, and at last broke with a weight of 280 lbs.
44278	224 293	54. Bro.			

Methods of Manufacturing Boiler Iron.

For the information of the general reader who may not be familiar with the several processes in the manufacture of iron, referred to in some of the preceding, and in several of the subsequent tables, it may be proper here to offer a few remarks explanatory of the methods pursued in the United States for producing wrought iron of the descriptions embraced in this part of the report.

It has already been stated that the iron furnished to the committee was, with a single exception, manufactured by the aid of charcoal. This remark applies, of course, to the first process, that of *smelting* it from the ore, which is, for the most part, performed in the usual blast furnaces from 30 to 40 feet in height, and about 8 feet in their greatest interior diameter, producing the different varieties of *pig metal.*

It has been mentioned to us, that in Missouri, this process is sometimes dispensed with, especially when working the ore of the "iron mountain," a rich, heavy, magnetic oxide, of a bluish or iron grey colour, and of the extraordinary specific gravity of 5.36. The ore is there put into open forge-fires resembling the Catalan Forges of the south of Europe, and by a similar treatment to that which there prevails, brought at once to the condition of malleable iron without passing through the state of *cast* or *pig* metal.

The process of manufacturing blooms, or, as they are, when intended for boiler plate, technically termed, "*blocks*," is to subject the pig metal of the blast furnace to the combined action of heat and air in an open forge-fire of charcoal, drawing off the melted cinder or "slag" by a suitable opening; and after stirring and compacting the iron as it begins to agglutinate, or "come round to nature," to carry the ball to the heavy forge-hammer, and form it into a prismatic mass, from 15 to 20 inches in length, and from 5 to 9 inches in diameter, according to the weight of the plate intended to be obtained from it. These *blocks* when taken to the rolling mill are heated in an air furnace supplied generally with bituminous coal as a fuel, and at the first heat are reduced by a heavy hammer into slabs 2 or 3 inches thick, and of a length nearly corresponding with that of the blocks. This operation discharges much of the remaining cinder, and other impurities left in the block by the *bloomery* treatment. At the second process they go to the *rolls* where they are placed first, with the length of the slab corresponding in direction with that of their axes; secondly, with the length of slab *across* the diameter of the rolls, until it has been increased to the required breadth of the finished sheet; and finally, by placing the original length of slab once more parallel to the axes, and extending the plate till it has been reduced to the requisite thickness.

Sheet iron by the process of *puddling*, is, for some purposes, manufactured from pig metal into malleable iron, without the intervention of any other process of refining, than that which takes place in the puddling furnace itself. But for boiler plate, it is believed to be customary, first to subject it to the action of the "run-out" refinery fire, in an open charcoal, or coke furnace urged by a powerful blast. As, in this fire, a large mass of metal is melted down at a time, and the cinder drawn off separately, the earthy impurities which in simple puddling would be retained in the balls, are at once removed, and by the aid of a small stream of water which is occasionally made to accompany the blast, a partial decarbonization of the metal is probably effected. When in full fusion, the metal is drawn off or "run out" into an oblong bed, and while still hot, is broken up into blocks of a few pounds weight each, to be conveyed to the puddling furnace. In the latter it under-

goes a second fusion, and the usual operations till agglutinated into "balls." Bituminous coal is the fuel here employed, and the furnace is of the reverberatory form. The balls pass from this furnace first to the large hammer, by which they are moderately compacted; and immediately after to the rolls, by which they are reduced into broad bars or slabs. The latter are reheated and at once rolled into plate, the former cut up into lengths of about 15 or 18 inches and piled, three high, to be reheated and welded into slabs of sufficient magnitude for plates of boiler iron.

Piled iron, when manufactured from *blooms*, does not, generally, it is believed, undergo a second hammering after being received at the rolling mill. At the first heat it is reduced to bars an inch or more in thickness, when it is cut up, piled as before mentioned, and rolled into plate.

The practice of *piling* appears to be followed, in some instances, from a supposition that a greater security from flaws and other blemishes, must result from combining the strength of three distinct laminæ—and fortifying the weak points of one by the strong parts of the two others, than could probably be derived from the simple unlaminated sheet, in which any imperfection would, it is supposed, extend through the entire thickness.—But the uncertainty of uniform welding between the members of a pile is sufficient to warrant some hesitation in approving this method. Table XXXIII., at experiments 12 and 13, affords evidence that the structure of this description of boiler iron is sometimes exceedingly imperfect, owing to a want of complete welding between the laminæ of which it is composed.

In a subsequent part of this report, will be found discussions on the relative influence of the different processes above described, and also on the *repetitions of piling* upon tenacity. It will there be seen that the practice of piling or *faggoting* may not in all cases prove detrimental to the iron, but will depend in some measure upon the degree of refining which it has previously undergone,—and its consequent freedom from earthy or other impurities which might interfere with accurate welding, as well as upon the temperature employed for that process. If, after reducing either *refinery blooms* or *puddled balls* to thin bars, fit for piling, there be made a perfect union of surfaces during this operation, the latter has evidently the advantage of affording to the impurities a more ready escape from interior portions of the metal, than would otherwise be obtained.

TABLE XLI.

Experiments on bars No. 81, 83, 84, 90 and 91. Manufactured at the Juniata Iron Works, near Pittsburg, by Messrs. Schoenberger & Son, from blooms by hammering and rolling. These strips were all cut

No. of the bar.	Direction of the slit.	No. of exp's.	DATE.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temp. Fah.	Breaking wt. in the scale.	Br. wht. X leverage.	Friction.	Effective strain.	Strength in pounds per sq. inch.
81	Cross.	1	1832. April 7.	24.075	.500	.186	.093000	65°	140	4200	210	3990	42904
81	"	2			.444	.182	.080808	65	133	3990	199	3791	46914
81	"	3			.440	.186	.081840	65	150	4500	225	4275	52236
81	"	4			.490	.184	.090160	65	200	6000	300	5700	63221
83	Cross.	5		24.0	1.014	.182	.184548	65	273	8190	409	7781	42162
83	"	6			.936	.184	.172224	65	296	8880	444	8436	48983
83	"	7			.988	.180	.177840	66	353	10590	529	10061	56573
84	Cross.	8		23.8	1.060	.182	.192920	66	289	8670	433	8237	42696
84	"	9		9.00	1.084	.182	.197288	66	319	9570	478	9092	46085
84	"	10		15.2	.990	.178	.176220	66	294	8820	441	8379	47548
90	Cross.	11	April 14.		.533	.247	.131651	600	263	7890	394	7496	56938
90	"	12			.679	.245	.166355	54	263	7890	394	7496	45060
90	"	13			.674	.252	.169848	54	328	9840	492	9348	55037
90	"	14			.608	.240	.145920	54	295	8850	442	8408	57620
90	"	15			.610	.245	.149450	50	270	8100	405	7695	51489
90	"	16			.585	.250	.146250	596	296	8880	444	8436	57682
91	Cross.	17		24.	1.072	.246	.263712	65	392	11760	588	11172	42365

TABLE XLI.

} *off crosswise of the sheet, and tried either at original or at detached filed sections. Specific gravity* 7.7580.

Wts. producing temporary elongation.	Elasticity of the bar.	Length after trial.	Area after trial.	REMARKS.
112 140	36.5′ Broke.		.500×.182 =.091000	This was a narrow strip and broke at an original section. do. do. do. do. do. do.
224 273	34. Broke.		1.014×.162 =.174408	The weight recorded was added by 7 lbs. at a time, not supposing the breaking weight to be nearly attained. The bar had borne 266 lbs. without signs of yielding. A filed section had been made .928 inch in breadth, and .180 thick, area 167040.
			.932×.162 =.150984	Broke at an original section.
345 353	10. Broke.		.988×.168 =.157034	The filed section had now been reduced to .904×.170=.153680. The section filed in the first experiment now bore 60231 lbs. per sq. inch without breaking, and calculating on its present area it bore 65467.
168 224 275 289	50. 52. 54. Broke.	24.05	1.046×.162 =.169452	A filed sect. in this bar had an area of .896×.176=.157696. Broke at an original sect. in the middle of the bar.
224 317 319	33. 24. Broke.	9.2	1.020×.160 =.163200	A filed section in the part now under trial has the dimensions .884×.178=.157352. Its strength as indicated by this trial was above 50421 lbs.
280 294	53. Broke.		.974×.160 =.155840	A section had been filed with the dimen. .884×.178=.157352, and giving a strength above 56046. Broke at an original section near the wedges.
				Temp. not very accurately noted at the instant of fract., believed to have been as high as numb. recorded. (600.) Broke at a filed section. The filed sect. not so deep as before. The filing still less than the preceding. Much deeper filing than either of the two preceding. The w'ht. is approximate only, as the bar broke instantly on applying 270 lbs; which was supposed its full load. Broke in tin at the filed section.
112 224 280 347 364 392	0.50.5′ 1.16. 1.00. 0.34. 0.20.5 Broke.	24.15		Broke at a section not filed.

TABLE XLII.

Experiments on bar No. 88. Manufactured at the Juniata Iron Works, near Pittsburg, by Messrs. Schoenberger & Son, from blooms, by hammering and rolling into boiler-plate. This strip cut off lengthwise of the sheet, and tried after having been reduced to a nearly }

Marks.	Breadth.	Thickness.	Area before trial.	Marks.	Breadth.	Thickness.	Area after trial.
				After the 2d fracture, 321 lbs.			
0	.741	.219	.162279	0	.635	.130	.082550
1	.767	.219	.167973	1	.752	.205	.154160
2	.767	.222	.170274	2	.756	.213	.161028
3	.767	.223	.171041	3	.769	.216	.166104
4	.766	.220	.168520	4	.767	.217	.166439
5	.767	.221	.169507	5	.768	.219	.168192
6	.764	.221	.168844	6	.759	.221	.167739
7	.771	.220	.169620	7	.762	.220	.167640
8	.768	.219	.168192	8	.750	.213	.159750
9	.769	.220	.169180	9	.759	.214	.162426
10	.767	.222	.170274	10	.755	.215	.162325
11	.765	.222	.169830	11	.758	.215	.162970
12	.769	.223	.171487	12	.763	.220	.167860
13	.769	.221	.169949	13	.761	.215	.163615
14	.770	.218	.167860	14	.761	.213	.162093
15	.769	.221	.169949	15	.763	.217	.165571
16	.768	.222	.170496	16	.761	.215	.163615
17	.771	.221	.170391	After the 6th fracture, 370 lbs.			
18	.767	.220	.168740				
19	.767	.221	.169507	3	.755	.212	.160060
20	.780	.228	.177840	4	.743	.204	.151572
				5	.752	.212	.159424
Mean of 21			.169611	6	.745	.213	.158685
				7	.753	.214	.160542
Maximum			.177840	8	.749	.210	.157290
Minimum			.162279	9	.746	.211	.157406
				10	.742	.208	.154336
Mn. of these 2			.170059				
Diff. of the 2			.015561				

The part from three to ten was, at the time of these measurements. 7.51 inches in length.

DATE.	No. of the experim'nt.	Area of the section of fracture before trial.	Temperature. Fah.
1832. Dec. 22,	1	.170391	610°
"	2	.162912	630
Dec. 29,	3	.169949	55
"	4	.167860	55
"	5	.170658	55
"	6	.170052	55
1833. Jan. 3,	7	.170657	61
"	8	.168521	61
"	9	.168520	61
"	10	.169103	61
"	11	.169507	61
Mean of 11 sections		.168921	

TABLE XLII.

uniform size by filing, and gauged at every inch, from 0 *to* 20. *Specific gravity*, 7.7922. *Original size before filing about* 1 *inch by* .25.

Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.	Points of fracture.	REMARKS.
296	8880	444	8436	49509	No. 17	Had been, during the experiment, for a short time as high as 630°. Part in tin from $11\frac{1}{2}$ to $15\frac{1}{2}$.
321	9630	481	9149	56159	" $0\frac{1}{9}$	Part in tin from 4 to 8.
346	10380	519	9861	58024	" 15	
353	10590	529	10061	59937	" 14	
358	10740	537	10203	59786	" $11\frac{1}{2}$	
370	11100	555	10545	62010	" $10\frac{1}{2}$	Slightly griped by the wedges at the section of fracture.
368	11040	552	10488	61457	" $2\frac{1}{2}$	Do.
385	11550	577	10973	65113	" $8\frac{1}{3}$	
385	11550	577	10973	65114	" 4	
383	11490	574	10916	64552	" $6\frac{1}{3}$	
320	9600	480	9120	53803	" 19	Part broken off in the first experiment. The mean area of the 11 sections of fracture is .000690 sq. inch *less* than the mean area of the 21 measured sections.

TABLE XLIII.

Experiments on bars No. 94, 95, 107, 108, 111, 112, 114 and 120, cut from plates of boiler iron, manufactured

No. of bar under trial.	Direction of the slit in cutting the bar.	No. of exp.	DATE.	Length of the bar before trial.	Breadth.	Thickness.	Area before trial of the section of fracture.	Temp. Fah.	Breaking weight in the scale.	Br. wt. X leverage.	Friction.	Effective strain.
94	L'gth.	1	1832. April 21,	24.07	1.074	.252	.270648	68.°	511	15330	766	14564
"	"	2	"		1.083	.252	.272916	70.75	550	16500	825	15675
"	"	3	"		1.060	.252	.267120	70.5	560	16800	840	15960
"	"	4	"		1.083	.252	.272916	73.75	574	17220	861	16359
"	"	5	"		1.062	.252	.267524	70.75	581	17430	871	16559
95	Cross.	6	April 25,	24.10	1.006	.238	.239428	62.25	382	11460	573	10887
"	"	7	June 10,		1.040	.241	.250640	79.5	431	12930	646	12284
"	"	8	"		1.060	.210	.222600	79.5	448	13440	672	12768
"	"	9	"		.792	.236	.186912	79.5	341	10230	511	9719
"	"	10	"		1.046	.237	.247902	79.5	493	14790	739	14051
107	Cross.	11			1.035	.072	.074520	70.75	145	4350	217	4133
"	"	12			.985	.078	.076830	70.75	151	4530	226	4304
"	"	13			1.083	.078	.084474	70.75	169	5070	253	4817
108	Uncer.	14		21.6	1.130	.076	.085880	62.	115.5	3465	173	3292
111	"	15		22.4	1.046	.146	.152716	62.	225	6750	337	6413
112	"	16		21.7	1.050	.136	.142800	62.	205.5	6165	308	5857
114	"	17			.914	.240	.219360	62.	469.4	14082	704	13378
120	"	18		22.8	.980	.272	.266560	62.	430.5	12915	645	12270

TABLE XLIII.

by R. Lukens, Chester Co. Pa. The sect's of frac. were those of the bars as they came from the shears.

Strength in pounds per squareinch.	Weights producing elongation.	Elasticity of the bar.	Length after trial.	Area after trial.	REMARKS.
53811	224 280 336 392 448 483 511	37′ 45 38 36 25 25 Broke.			
57435				1.068×.212 =.226416	Broke within the wedges. Area after fracture 83 per cent. of the area before trial.
59748				.989×.201 =.198789	Area after fracture, 70 per cent.
59941				.994×.190 =.188860	This fracture developed a remarkably clear and compact structure. Area 69 per cent.
61897				.990×.223 =.220770	Area after fracture, 82 per cent.
45471	224 336 382	34 26 Broke.	24.19	.970×.214 =.207580	Area after fracture, 87 per cent.
48994				.973×.200 =.194600	Area after fracture, 77 per cent.
55184				1.030×.208 =.214240	Broke at an original section. Area after fracture .96 per cent.
51998				.765×.213 =.162945	Area after fracture, 87 per cent.
56680				1.050×.209 =.219450	Area after fracture, 89 per cent.
55461				1.035×.070 =.072450	Broke at an original section; a filed section had been made =.985×.978=.077830, which tho' smaller in one direction was greater in the other, and of greater area than the section of fracture. Area after fracture, 97 per cent.
56020				.954×.066 =.062964	Area after fracture, 70 per cent.
57035				1.083×.061 =.066063	Area after fracture, 78 per cent.
38332			22.6	1.030×.062 =.063860	Area after fracture, 74 per cent.
41926			22.8	.994×.110 =.109340	Area after fracture, 71 per cent.
41015			22.5		
60986					
46031			23.5		The mean area of the sections of fracture *after trial* is 80.7 per cent. of the mean area of the same sections *before trial.*

TABLE XLIV.

Experiments on bars No. 125, 130, 133, 135 and 137. Manufactured by Messrs. S. E. H. & P. Ellicott, of Baltimore. The ore obtained on the Patapsco, 8 miles from Balt., reduced at Elkridge furnace, and forged at Patuxent forge, in the neighbourhood of that city. A slab was drawn out under the ham-

No. of the bar.	Direction of the slit.	No. of exp.	DATE.	Length before trial.	Breadth.	Thickness.	Area of section before trial.	Temperature Fah.	Br. weight in the scale.	Br. weight × leverage.	Friction.	Effective strain.
			1832.									
125	L'gth,	1	June 13.		1.060	.150	.159000	394.°	319	9570	478	9092
125	"	2	"		.982	.154	.151228	394.	336	10080	504	9576
125	"	3	"		.982	.154	.151228	82.	350	10500	525	9975
130	Cross.	4		16.6	1.052	.248	.260896	60.	529	15870	793	15077
133	Cross.	5	June 20.		1.003	.130	.130390	214.	259	7770	388	7382
133	"	6	"		.900	.137	.123300	214.	265	7950	397	7553
133	"	7	"		1.022	.140	.143080	394.	284	8520	426	8094
133	"	8	"		.817	.150	.122550	74.	300	9000	450	8550
133	"	9	"		.890	.165	.146850	74.	274	8220	411	7809
135	Diag.	10			.462	.247	.114114	78.	249	8470	423	8047
135	"	11		24.	1.020	.247	.251940	84.	422	12666	633	12027
135	"	12			1.012	.247	.249964	84.	442	13260	663	12597
135	"	13			1.012	.247	.249964	84.	451	13530	676	12854
135	"	14			1.012	.247	.249964	84.	451	13530	676	12854
137	Diag.	15	June 13.		1.040	.271	.281840	79.5	498	14940	747	14193
137	"	16	"		.950	.248	.235600	80.	469	14070	703	13367
137	"	17	"		.972	.262	.254664	212.	529	15870	793	15077
137	"	18	"		.850	.254	.215900	212.	515	15450	772	14678

TABLE XLIV.

mer and cut in three different ways, viz. 125 longitudinally *with the grain;* 130 *and* 133 *transversely, and* 135 *and* 137 diagonally. *The pieces thus cut off, subsequently drawn with the small hammer to nearly the size indicated in the column of areas. In some instances, reduced by filing at particular sections.*

Strength in lbs. per sq. inch.	Wt. producing temporary elongation.	Elasticity of the bar.	Length after trial.	Area of the section of fracture after trial.	REMARKS.
57182				.892 × .091 = .081172	Broke out of the oil—near the wedges.
63322					Do. do. Calculating on the filed section, we find it bore the w'ght per in. here noted. As the actual section of fracture was not gauged before trial, we cannot determine precisely the str'gth at that point.
65960				.840 × .089 = .074760	Broke at the filed section.
57789	56	08.′	16.6	.952 × .210 = .199920	The elasticity under a weight of 336 lbs. in the scale, was taken after the weight had been suspended 15 hours.
	112	08.5			
	168	09.	16.6		
	224	11.	16.6		
	280	13.5			
	336	12.			
	436	16.			
	466	12.	16.725		
	485	16.			
	506	24.	16.975		
	529	Broke.	17.13		
56614				.893 × .091 = .081203	Broke outside of the oil at a filed section not the *smallest.*
61168				.775 × .090 = .069750	Broke in oil at filed section.
56570				.921 × .100 = .092100	Broke out of the filed section at a thick part of the bar.
69767				.723 × .100 = .072300	Broke at filed section.
53176				.728 × .104 = .075712	Broke at a filed section.
70517				.368 × .153 = .056304	The strength deduced, is that of the smallest filed section. The section actually fractured, was .510 × .247 = .125970 giving a strength of 63880 lbs.
47738				.790 × .150 = .118400	Before this fracture the bar had been extended 1.9 inches.
50039				.787 × .160 = .125920	The whole bar had now become irregular with alternate large and small sections.
51423				.825 × .168 = .138600	No stretching except very near the section of fracture.
51423				.800 × .178 = .142400	Point of fracture obs'd to be very warm.
50358	490	44.′		.802 × .176 = .141152	Original section, as hammered.
	498	Broke.			
56736	336	20.		.772 × .158 = .121996	Filed section.
	420	40.			
	469	Broke.			
59203					Heated in oil to 212°. Broke outside of the oil, near the wedges.
67939				.745 × .170 = .126650	Broke in the oil at the filed section. The mean area of the 16 sections after fracture is 55.6 per cent. of the corresponding areas before trial.

TABLE XLV.

Experiments on bars No. 148, 151, 167 *and* 169. *Manufactured by S. E. H. & P. Ellicott. The ore obtained on the Patapsco,* 8 *miles from Baltimore. Rolled in the usual manner into boiler plate, and these strips*

No. of the bar.	Direction of the slit.	No. of the experiment.	DATE.	Length of the bar before trial.	Breadth.	Thickness.	Area of the section before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.
148	Cross.	1	1832. May 2,		1.006	.250	.251500	64°	463	13890	694	13196	52468
148	"	2	"	20.6	.994	.250	.248500	64	476	14280	714	13566	54591
148	"	3	"		.755	.243	.183465	394	449	13470	673	13797	69752
148	"	4	"		.690	.253	.174570	81	399	11970	598	11372	65143
151	Cross.	5	"	30.5	1.008	.250	.252000	64	476	14280	714	13566	53811
151	"	6	"	29.8	1.016	.250	.254000	64	489	14670	733	13937	54868
151	"	7	"		.958	.248	.237584	64	503	15090	754	14336	60344
151	"	8	"		1.036	.250	.259000	64	503	15090	754	14336	54820
151	"	9	"		1.008	.248	.249984	64	504	15120	756	14364	57459
167	Cross.	10	May 9,	30.4	.942	.160	.150720	69	292	8760	438	8322	55222
167	"	11	"	27.2	1.004	.156	.156624	69	296	8880	444	8436	53862
167	"	12	"	19.33	.992	.156	.154752	69	307	9210	460	8750	56539
169	Cross.	13	"	30.1	1.032	.132	.136224	69	240	7200	360	6840	50212
169	"	14	"		1.032	.132	.136224	69	240	7200	360	6840	50212
169	"	15	"		1.032	.132	.136224	69	240	7200	360	6840	50212
169	"	16	"		1.000	.132	.132000	69	240	7200	360	6840	51818
169	"	17	"		1.000	.132	.132000	69	254	7620	381	7239	54841
169	"	18	"		1.020	.132	.134640	69	277	8310	415	7895	58839

TABLE XLV.

cut off with the shears across the direction of rolling. Reduced by filing from about one inch in breadth, in some of the experiments to the sections recorded; in others the bars left as they came from the shears.

Weights producing elongation.	Elasticity of the bar.	Length after trial.	Area of the section after fracture.	REMARKS.
212	29′			
336	33			
392	42		.248000	Fracture at an original section.
448	45			
463	Broke.			
463	37′	20.9	.205792	Broke at the smallest section, fracture compound.
476	Broke.			
				Broke suddenly at the filed section, but not by any sudden addition of weights.
				Broke at the filed section, a fair experiment.
224	30′			
336	33	30.9	.225096	A filed section was made near one end of the bar but the fracture took place near the other end.
448	40			
476	Broke.			
476	36′		.224200	Broke partly within the wedges.
489	Broke.			
			.185120	Broke at the *filed section*. The four other sections show 8.4 per cent. less strength on an average than this.
			.208320	Broke at an unfiled section.
			.220000	Do. do.
224	38′			
266	36	31.1	.097812	Section filed in the breadth, fracture much warmer than the hand at the moment of breaking.
284	42			
292	Broke.			
		27.33	.114228	Original section, fracture warm.
306	29′	19.4	.112840	Broke at the smallest section.
307	Broke.			
			.096200	Broke at two places at a distance from each other. All the fractures on this bar were made at *original* or unfiled sections.
			.116560	
			.121088	Two fractures occurred simultaneously near each other.
253	44′		.095800	
254	Broke.		.112632	
			.125748	
				The whole bar has now been extended from 30.1 to 31.3 inches by these six fractures. The number of points actually separated was 8, two fractures having twice occured at the same moment.

TABLE XLVI.

Experiments on bars No 154, 157, 171 and 174, and Nos. 142 and 143. Manufactured by Messrs. S. E. H. & P. Ellicott. The ore obtained on the Patapsco, 8 miles from Baltimore, rolled into boiler-plate in the usual manner. The first four strips cut off diagonally, and the last two longitudinally with the

No. of the bar.	Direction of the slit.	No. of exp.	DATE.	Length before trial.	Breadth.	Thickness.	Area before trial.	Temperature, Fah.	Br. weight in the scale.	Br. weight X leverage.	Friction.	Effective strain.	Strength in lbs. per sq. inch.
154	Diag.	1	1832. May 5.	30.4	.952	.250	.238000	60.°	427	12810	640	12170	51134
154	"	2	"	23.08	.960	.250	.240000	60.	438	13140	657	12483	52012
154	"	3	"		.900	.250	.225000	60.	464	13920	696	13224	58773
157	Diag.	4	"	30.35	1.024	.250	.256000	62.	468	14040	702	13338	52102
157	"	5	"		1.000	.250	.250000	66.5	469	14070	703	13367	53468
171	Diag.	6	May 12.	30.2	.960	.134	.128640	69.	251	7530	37 6	7154	55612
174	Diag.	7	"	30.2	.896	.132	.118272	69.	235	7050	352	6698	56632
174	"	8	"	27.7	.972	.134	.130248	69.	235	7050	352	6698	51425
174	"	9	May 19	23.9	.974	.134	.130516	69.	246	7380	369	7011	53717
174	"	10	"	22.1	.956	.136	.130016	69.	246	7380	369	7011	53924
142	L'gth.	11	Ap. 18.	30.4	1.110	.240	.266400	62.	415	12450	622	11828	44399
143	L'gth.	12	Ap. 25.	30.6	1.000	.236	.236000	62.	440	13200	660	12540	53135
143	"	13	"	29.3	1.034	.236	.244024	62.	478	14340	717	13623	55826
143	"	14	"		.944	.238	.224672	62.	478	14340	717	13623	60635
143	"	15	May 2.		1.014	.236	.239304	64.	495	14850	742	14108	58954

TABLE XLVI.

sheets. Tried either at original sections, or at points more or less reduced by filing from the breadth a semicircular cavity on each edge. The bars originally cut one inch wide.

Wt. producing ten. elongation.	Elasticity of the bar.	Length after frac.	Area after trial.	REMARKS.
224 336 392 420 427	30.′ 30. 38. 42. Broke.	30.52	.215740	Did not break at the smallest section.
392 438	21. Broke.		.212676	Do.
434 449 459 464	22. 25. 26.5 Broke.		.189200	Broke *near* the smallest section.
224 336 392 420 438 448 462 468	27. 50. 50. 51. 49. 45. 46.5 Broke.	31.0	.994×.212 =.210728	A section was filed in the breadth of the bar so as to leave an area of .962×.25=.240500 of a sq. inch; while the smallest original section was 1.015×.248=.251968, and the section actually broken was .256000. Calculating on the filed section we obtain a strength of more than 55459, because the bar was *not broken* at that point. This on the same filed section shows a strength a little above that calculated in the preceding remark.
224 251	18. Broke.	30.5	.962×.122 =.117364	Broke in the middle of the bar.
219 227 235	44.5 50.5 Broke.	30.7	.796×.102 =.081192	Filed.—Broke at the filed section.
231 235	1.05 Broke.	27.9	.950×.120 =.114000	Do. do.
231 245 246	41. 44. Broke.	24.1	.950×.114 =.108300	Do. do.
245 246	39. Broke.	22.3	.934×.116 =.108344	Do. do.
112 224 280 336 364 380 398 415	08.5 14. 15. 27. 26.5 32. 31.5 Broke.	31.1	1.09×.230 =.250700	Original section.
224 280 336 370 392 435 440 440	30. 33. 48. 53. 52. 44. 47. Broke.	31.3		Did not break at the smallest section. After the elasticity had been taken under 440 lbs. the same weight broke the bar.
464 478	41 Broke.		.994×.186 =.184884	Did not break at the filed section, though its area was only .944×.238=.224672.
			.800×.152 =.121600	Br. at the filed section noted in the preceding remark.
485 485 495 495	37.5 33.5 36.5 Broke.		.990×.214 =.211860	The elasticity may be very slightly erroneous, as the index rose a little way above the top of the scale. When the bar appeared to be giving way under 494 lbs., 9 lbs. were taken off, so as to leave 485, with which the elasticity was again tried, and found to be 33.6′. Having restored the 9 lbs. the elasticity was again tried, and found 34.5′ for the whole weight.

TABLE XLVII.

Experiments on bars No. 160, 162, *and* 164. *Manufactured by S. E. H. & P. Ellicott. The ore was obtained on the Patapsco,* 8 *miles from Baltimore, rolled into boiler plate in the usual manner,*

No. of the bar.	Direction of the slit.	No. of the experiment.	DATE.	Length of the specimen before trial.	Breadth of the section before trial.	Thickness before trial.	Area of the section before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight X leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.
160	L'gth.	1	1832. May 2.	30.2	.862	.136	.117232	60°	245	7350	367	6983	59565
160	"	2	"	27.2	.946	.126	.119196	60	250	7500	375	7125	59775
160	"	3	"	22.25	1.000	.130	.130000	60	257	7710	385	7325	56346
160	"	4	"		.612	.124	.075888	48	175	5250	262	4988	65725
160	"	5	May 7.		1.016	.130	.132080	60	272	8160	408	7752	58691
160	"	6	"		1.040	.134	.139360	60	290	8700	435	8265	59307
162	L'gth.	7	May 9.	30.2	.858	.136	.116688	69	256	7680	384	7296	62526
162	"	8	"	27.6	.998	.132	.131736	69	262	7860	393	7467	56682
162	"	9	1833.	19.4	1.000	.136	.136000	69	280	8400	420	7980	58677
162	"	10	Jan. 24.		.647	.134	.086698	48	225	6750	337	6413	73969
162	"	11	"		.750	.114	.085500	49	234	7020	351	6669	78000
162	"	12	Jan. 26.		.656	.130	.085280	56.5	224	6720	336	6384	74859
164	L'gth.	13			.747	.132	.098604	576	233	6990	349	6641	66336
164	"	14			.711	.135	.095985	87.5	203	6090	304	5786	60280
164	"	15			.731	.138	.100878	87.5	200	6000	300	5700	56503
164	"	16			.734	.140	.102760	87.5	196	5880	294	5586	54361
164	"	71			.780	.139	.108420	578	253	7590	379	7211	66510
164	"	18			.683	.135	.092205	74.	198	5940	297	5643	61200
164	"	19			.714	.135	.096390	74.	208	6240	312	5928	61500

TABLE XLVII.

(method of refining not stated.) These strips cut off lengthwise *of the sheet. Reduced in some instances by filing, and in others tried in the state in which they came from the shears. Specific gravity* 7.7.

Weight producing extension.	Elasticity of the bar indicated by the recoil.	Length of the bar after trial.	Area of the section of fracture after trial.	REMARKS.
224	$1^{\circ}.22'$	30.85	.079764	Broke at a filed section.
245	Broke.			
			.090240	Do.
252	$1.04'$	27.3	.096304	Do.
257	Broke.			
				Deeply filed section, bore 175 pounds, for a while sunk from 0 with it, but broke on taking up the screw.
262	$0.42'$		.101388	Unfiled section.
272	Broke.			
280	$0.35'$		.128000	Do.
290	Broke.			
168	$1^{\circ}.00'$	30.8	.079600	Broke at the filed section. * This elasticity taken within 4 lbs. of the breaking weight.
224	1.05			
252	0.58*			
256	Broke.			
262	$1^{\circ}.12'$	28.0	.103800	A section was filed on the sides to remove completely the scale of oxide from the bar at that part. But the fracture did not take place at the filed section though its area was only .116820; while that of the section of fracture was .131736. Calculated on the section filed, the strength was *above* 63917 lbs per square inch.
262	Broke.			
		19.7		Original section.
				This experiment was on a deeply filed section.
				Do.
				Bore this weight for some time and then broke without addition.
			.068701	Fracture at the filed section forming a bevel like the cutting part of a mortising chisel.
			.047333	Fracture of the usual appearance of *cold* bars.
			.042560	Do.
			.041400	Broke immediately on applying this weight.
			.067800	This fracture smooth and sharp like the first experiment and of the same form.
			.043500	Fracture as usual in cold experiments.
			.048030	Do. Do.

TABLE XLVIII.

Experiments on bar No. 146. *Manufuctured by Messrs. S. E. H. & P. Ellicott. Rolled into boiler plate in the usual manner, and this strip cut off lengthwise of the sheet. Reduced by filing, after having been cut with the shears. The dimensions of the specimen before trial*

Dimensions taken after certain exp's. had been made or given whts. borne by the bar.

Measures after a strain of 328 pounds. Oct. 17, 1832.

Marks.	Breadth.	Thickness.	Area.
1	.888	.200	.177600
5	.888	.200	.177600
8	.891	.200	.178200
12	.882	.204	.179928
13	.882	.203	.179046
17	.880	.209	.183920
20½	.886	.209	.185174
24½	.882	.207	.182574

Meas. taken after first frac.

Marks.	Breadth.	Thickness.	Area.
1	.875	.198	.173250
2	.881	.196	.172676
3	.883	.200	.176600
4	.883	.197	.173951
5	.879	.200	.175800
6	.874	.200	.174800
7	.873	.200	.174600
8	.880	.200	.176000
9	.879	.201	.176679
10	.879	.202	.177558
11	.867	.201	.174267
12	.867	.200	.173400
13	.805	.191	.153755
13½	.788	.165	.130020
14	.845	.198	.167310
15	.862	.201	.173262
16	.868	.204	.177072
17	.865	.205	.177325
18	.880	.203	.178640
19	.872	.201	.175272
20	.875	.203	.177625
21	.874	.201	.175674
22	.884	.202	.178568
23	.883	.207	.182781
24	.866	.207	.179262
25	.873	.205	.178965

After the second fracture.

Marks.	Breadth.	Thickness.	Area.
1	.874	.198	.173052
2	.865	.196	.169540
3	.867	.192	.166464
4	.869	.192	.166848
5	.868	.199	.182732
6	.857	.199	.170543
7	.857	.195	.167115
8	.866	.197	.170602
9	.873	.202	.176346
10	.866	.200	.173200
11	.865	.198	.171270

After the fourth fracture.

Marks.	Breadth.	Thickness.	Area.
1	.870	.197	.171390
2	.856	.193	.165208
3	.848	.190	.161120
3½	.847	.187	.158389
4	.855	.192	.164160
5	.860	.195	.167700
6	.843	.198	.166914

After the seventh fracture

Marks.	Breadth.	Thickness.	Area.
1	.862	.196	.168952
2	.854	.192	.163968
3	.848	.189	.160272
3¼	.846	.187	.158202
4	.855	.192	.164160
5	.859	.196	.168364

After the 6th experiment.

Marks.	Breadth.	Thickness.	Area.
16	.861	.201	.173061
17	.856	.201	.172056
18	.873	.202	.176346
19	.868	.200	.173600
20	.856	.200	.171200
20½	.854	.200	.170800
21	.858	.199	.170742
22	.869	.200	.173800
23	.866	.200	.173200
24	.848	.197	.167056
24½	.838	.199	.166762
25	.863	.201	.173463

After the tenth fracture.

Marks.	Breadth.	Thickness.	Area.
16	.844	.202	.170488
17	.852	.201	.171252
18	.866	.202	.174932
19	.851	.200	.170200
20	.854	.199	.169946
21	.855	.197	.168435
22	.863	.200	.172600
23	.861	.201	.173061
24	.794	.180	.142920

During the 14th experiment, smallest section.

Marks.	Breadth.	Thickness.	Area.
	.835	.193	.161155
18	.864	.200	.172800

No. of the experiment.	DATE.	Temp. Fah.
1	1832. Oct. 20.	56°6
2	"	580
3	Oct. 27,	545
4	"	550
5	Nov. 3,	580
6	"	560
7	Nov. 10,	52
8	"	52
9	"	52
10	"	547
11	"	500
12	Nov. 15,	90
13	"	80
14	"	70

TABLE XLVIII.

were, length 25½ *inches, breadth* .893, *and thickness* .207, *giving the area of cross sections*=.184851 *of a square inch. Marked and numbered before trial at every inch of the length. Spec. grav.* 7.739. *Original dimensions before filing*, 1.01×.24=.242400, *area of section.*

Breaking weight in the scale.	Br. weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
393	11790	589	11201	60594	No. 13¾	Part in hot oil from 1 to 5; in ice from 20½ to 24½. Strained with 328 lbs. then gauged as stated. Increase of length by that wht. .3 inch in 25.5. When the oil was 566,° the part at No. 9 was at 212°.
424	12720	636	12084	65371	" 12	When put in, this piece measured 13.85 inches in length. After frac. it was 14.6.
437	13110	655	12455	67378	Broke between the wedges.	This fracture took place at the coldest part, say at about 100°. After frac. one portion, viz. from 9 to 10, was found to measure in Breadth. .760, Thick. .163, Area .123880.
446	13380	669	12611	68222	" 6½	Before this fracture was made, the bar had been put under a strain of 429 lbs. and a temperature of 545°. Then suffered to cool down to 56°. By again heating it up to 446 the index fell 33′, and by raising the temperature to 540° it fell in all 48′.
405	12150	607	11543	62445	" 15.1	Fracture near the wedges. This and the following experiment were made on a different part of the bar from the preceding.
431	12930	646	12284	66453	Not parted.	Part in oil from 14 to 18. At the temp. and wht. here recorded the oil accidentally took fire, which caused the experiment to be suspended. The bar was subsequently heated again in experiment 10th.
462	13860	693	13167	71253	At a part ungauged near No. 1.	After this experiment this part of the bar was again gauged.
463	13890	694	13196	71387	" 5½	Fracture just within the wedges.
469	14070	703	13367	72312	" 5	Frac. very bright and crystalline–directly across–with little diminution of aréa–a flaw now appears in this part of the bar.
467	14010	700	13310	72004	" 24	Part now in, is from 16 to 24½, same part in oil as in the 6th experiment.
464	13920	696	13224	71539	Within the wedges.	The point of frac. was judged to be heated to above 130° as it could not conveniently be held in the hand.
476	14280	714	13566	73389	Not noted.	The temperature marked in this experiment is only *approximate*.
477	14310	715	13595	73546	Do.	
485	14550	727	13823	74779	Near 18.	After the weight 485 had been applied the bar was taken out and gauged, then returned and broke, but not at the smallest sect.

TABLE XLIX.

Experiments on bar No. 149. Manufactured into boiler plate by Messrs. S. E. H. & P. Ellicott. The ore obtained on the Patapsco, 8 miles from Baltimore; rolled in the usual manner, and this strip cut

Marks.	Breadth	Thickness.	Area before trial at the points measured.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight multiplied by leverage.	Friction.	Effective strain.
0	.762	.248	.188976		1833.						
1	.762	.247	.188214	1	Oct. 10,	.180357	66	334	10020	501	9519
2	.760	.242	.183920								
3	.760	.242	.183920								
4	.760	.243	.184680	2	"	.182259	750	334	10020	501	9519
5	.761	.248	.188728				approx.				
6	.760	.248	.188480	3	Oct. 12,	.184680	61	369	11070	553	10517
7	.760	.245	.186200	4	"	.186770	61	371	11130	556	10574
8	.760	.243	.184680	5	"	.183920	62	375	11250	562	10688
9	.761	.237	.180357	6	"	.188666	62	380	11400	570	10830
10	.762	.242	.184404								
11	.762	.246	.187452								
12	.762	.240	.182880	7	"	.185669	825	369	11070	553	10517
13	.762	.237	.180594								
14	.762	.239	.182118								
15	.760	.240	.182400	8	"	.182309	63.5	380	11400	570	10830
16	.760	.240	.182400								
17	.761	.240	.182640								
18	.761	.239	.181879								
19	.762	.240	.182880	9	"	.183381	770	356	10680	534	10146
20	.763	.240	.183883								
21	.763	.244	.186172								
22	.764	.241	.184124								
23	.763	.243	.185409	10	Oct. 17,	.182400	69	397	11910	595	11315
24	.763	.245	.186935	11	"	.182630	69	397	11910	595	11315
25	.762	.242	.184404	12	"	.184455	69	403	12090	604	11486
26	.762	.240	.182880	13	"	.185088	69	410	12300	615	11685
27	.762	.238	.181356	14	"	.182118	69	401	12030	601	11429
28	.762	.239	.182118								
29	.769	.235	.180715		Mn. of 14 =	.183907					
Mean of 30			.184193								
Maximum			.188976								
Minimum			.180357								
Mn. of the 2			.184666								
Diff. of the 2			.008619								

TABLE XLIX.

off by the shears across the direction of the rolling. Reduced by filing from about one inch in breadth and $\frac{1}{4}$ inch in thickness to the dimensions recorded. Specific gravity, 7.7774.

Strength in lbs. per sq. inch.	Point of fracture.	REMARKS.
52778	No. 9	More than 24 inches under trial. After several trials to ascertain the weight producing the first permanent extension, it was found to be attained with 224 pounds in the scale.
52228	" 14½	Part in tin from 13 to 16½. Too much water in the pyrometer---dashed over a little. The No. 780+212, originally marked, is certainly too high.
56947	" 8	The part now under trial was that broken off in the first exp.
56615	" 6¾	
58112	" 2⅓	
57403	" 5¼	
56644	" 24½	The part now in is from 22 to 25½. The bar stretched for some time, and as the furnace was not lowered, the standard piece had probably at the moment before taking the temperature, attained a greater degree of heat than was absolutely necessary to break the bar under this weight.
59494	" 12¼	
54781	" 19½	Part in metal from 18 to 21. The temperature was raised gradually until the bar appeared about to give way; then lowered the furnace and diminished the heat till the lever ceased to descend. Repeated this three times and at last when a decided evidence of fracture was given the temperature was taken with care, and is therefore regarded as very correct.
62034	" 15½	
61955	" 18¾	
62269	" 20¼	Broke in the gripe of the wedges.
63132	" 22¾	
62755	" 28	
		The mean area of the sections of fracture is .000286 square inch *less* than the mean area of the measured sections.

TABLE L.

Experiments on bar No. 150. Manufactured by Messrs. S. E. H. & P. Ellicott. The ore obtained on the Patapsco, 8 miles from Baltimore. Rolled in the usual manner, and this strip cut off by

Marks.	Breadth.	Thickness.	Area of section at the points gauged before trial.	DATE	No. of the exp't.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.	Weight producing elongation.
0	.719	.236	.169684										196
1	.720	.236	.169920										294
2	.721	.236	.170156										301
3	.718	.237	.170166										308
4	.720	.234	.168480	1833. Sept. 26,	1	.166020	81°	346	10380	519	9861	59397	315
5	.717	.236	.169212										322
6	.722	.236	.170392										329
7	.722	.236	.170392										336
8	.722	.235	.169670										343
9	.721	.234	.168714										346
10	.718	.234	.168012										
11	.717	.232	.166344	"	2	.169485	662	346	10380	519	9861	58182	
12	.721	.232	.167272										
13	.719	.232	.166808	"	3	.168470	75	345	10350	517	9833	58366	
14	.717	.231	.165627										
15	.724	.232	.167968	"	4	.166808	75	380	11400	570	10830	64925	
16	.724	.232	.167968	"	5	.170301	734	346	10380	519	9861	57903	
17	.723	.231	.167013										
18	.721	.230	.165830	Sept. 28,	6	.168714	68	368	11040	552	10488	62164	
19	.721	.232	.167272	"	7	.167272	68	382	11460	573	10887	65086	
20	.722	.234	.168948	"	8	.170392	68	340	10200	510	9690	56869	
21	.723	.235	.169905	"	9	.169605	68	361	10830	541	10289	60664	
22	.722	.233	.168226	"	10	.169684	68	368	11040	552	10488	61809	
23	.721	.234	.168714	"	11	.169920	68	377	11310	565	10745	63235	
24	.723	.237	.171351										
25	.725	.237	.171825										
26	.722	.233	.168226	"	12	.170166	68	388	11640	582	11058	64983	
27	.720	.234	.168480										
28	.719	.232	.166808										
				Oct. 3,	13	.167226	63	386	11580	579	11001	65785	
Mean of 29 =			.168599	"	14	.170692	63	388	11640	582	11058	64783	
				"	15	.168311	63	388	11640	582	11058	65700	
Maximum =			.171825										
Minimum =			.166344										
				"	16	.167963	63	359	10770	538	10232	60917	
Mn of these 2			.169084										
Diff. of the 2			.004491	"	17	.167272	63	372	11160	558	10602	63382	
				"	18	.166615	63	382	11460	573	10887	65342	
					Mn. of 18 =	.168606							

TABLE L

the shears, across the direction of the rolling. Reduced by filing from about one inch in breadth and one-fourth inch in thickness, to the dimensions recorded. Specific gravity, 7.7774.

Observed elongations of the bar under the several weights.	Point fractured.	REMARKS.
1st perm. elong. .30 in 24 in. .40 " .50 " .60 " .73 " .90 " 1.14 " 1.42 " Br. as per rec.	No. $13\frac{2}{3}$	
	" $21\frac{1}{4}$	The temperature is perhaps not quite accurate on account of the standard piece having fallen. Part in tin from 19 to 23. *Broke in the tin.*
	" $22\frac{1}{2}$	Broke at a part which had been heated.
	" $28\frac{1}{2}$	
	" $7\frac{5}{8}$	Part in tin from $4\frac{1}{2}$ to $8\frac{1}{2}$.
	" 9	
	" 12	
	" $6\frac{1}{4}$	Broke very soon after the weight was applied.
	" $5\frac{1}{3}$	
	" 0	Not heated.
	" 1	
	" 3	When the weight had been added to the amount of 383 lbs. the machine was relieved and oiled to ascertain whether the friction had before been above our estimate; but no effect was perceptible.
	" $27\frac{3}{4}$	
	" $23\frac{3}{4}$	
	" $26\frac{1}{3}$	
	" 15	Part now under trial from $13\frac{2}{3}$ to 21. Fracture shows three distinct laminæ, of which the central one appears more coarse grained than the two outside ones.
	" 19	
	" $17\frac{1}{3}$	
		The mean area of 18 fractures, is .000007 square inch *greater* than the mean area of the 29 measured sections.

TABLE LI.

Experiments on bar No. 152. Manufactured by Messrs. S. E. H. & P. Ellicott. The ore obtained on the Patapsco, eight miles from Baltimore. Rolled into boiler plate and this strip cut across the sheet.

Marks.	Breadth.	Thickness.	Area of section at the points measured.	No. of the experiment.	DATE.	Area of the section of fracture.	Temp. Fah.	Breaking wht. in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per sq. inch.
0	.733	.232	.170056		1833.							
1	.733	.233	.170789	1	Sept. 14.	.171230	66°	348	10440	522	9918	57922
2	.733	.235	.172255									
3	.733	.235	.172255	2	"	.173327	66	341	10230	511	9719	56073
4	.733	.235	.172255									
5	.731	.236	.172516	3	"	.173195	66	348	10440	522	9918	57405
6	.735	.236	.173460									
7	.729	.236	.172044	4	"	.172752	722	330	9900	495	9405	54442
8	.735	.236	.173460									
9	.735	.236	.173460									
10	.735	.234	.171990	5	Sept. 19.	.169050	1037	224	6720	336	6384	37764
11	.735	.231	.169785									
12	.735	.233	.171255									
13	.735	.235	.172725									
14	.735	.233	.171255	6	Sept. 21.	.172490	80	336	10080	504	9576	55516
15	.735	.230	.169050									
16	.735	.233	.171255	7	"	.170770	80	350	10500	525	9975	58412
17	.735	.230	.169050									
18	.734	.235	.172490	8	"	.171990	80	336	10080	504	9576	55678
19	.737	.236	.173932									
20	.737	.235	.173195	9	"	.172358	80	340	10200	510	9690	56220
21	.737	.235	.173195									
22	.737	.235	.173195	10	"	.171990	80	373	11190	559	10631	61809
23	.735	.236	.173460									
24	.735	.233	.171255	11	"	.170056	80	352	10560	528	10032	58992
25	.736	.233	.171488									
26	.737	.233	.171721	12	"	.173106	80.5	375	11250	562	10688	61742
27	.737	.232	.170984									
28	.738	.230	.169740	13	"	.172342	80.5	379	11370	568	10802	62677
Mean of 29			.171847	14	"	.172255	80.5	379	11370	568	10802	62709
Maximum			.173932		Mn. of 14 =	.171922						
Minimum			.169050									
Mn. of these 2			.171491									
Diff. of the 2			.004882									

TABLE LI.

Reduced by filing from one inch in breadth to the dimensions recorded, and gauged at every inch, from 0 *to* 28 *inclusive. Specific gravity*, 7.7774.

	Point fractured.	REMARKS.
	No.	
	$26\frac{2}{3}$	
	$22\frac{1}{2}$	Broke very soon after applying the wht. recorded.
	$20\frac{3}{4}$	Broke by a gradual application of weights.
	$7\frac{1}{2}$	Fracture oblique to the bar.
Measured after this exp. .640 (87 per cent. of ori. br'th.) | .198 (81.7 pr. ct. of ori. thick.) | .126720 (74.3 per ct. of the original area.)	15	At this trial the condenser of the steam pyrometer was employed. When the equilibrium had been reproduced by the revolving weight it continued without the slightest alteration for half an hour.
	18	Broke at the part heated—a flaw discovered in the interior of the bar.
	$17\frac{1}{2}$	
	$13\frac{1}{2}$	Broke on first applying the weight—result supposed rather too high.
	$12\frac{3}{4}$	
	10	
	0	
	$6\frac{1}{4}$	
	$4\frac{1}{3}$	
	$3\frac{3}{4}$	The mean area of the sections of fracture is .000075 *greater* than the mean area of the 29 measured sections.

TABLE LII.

Experiments on bars No. 200 *and* 201, *cross strips, and on* 206, 207
Gerard Ralston, Esq.

No. of the bar.	Direction of the slit.	DATE.	No. of the exp't.	Breadth before trial.	Thickness before trial.	Areas of section before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
200	Cross.	1833. Aug. 4,	1	.760	.160	.121600	81.°	226	6780	339
200	"	"	2	.658	.160	.105280	81.	190	5700	285
200	"	"	3	.778	.166	.129148	81.	182	5460	273
201	Cross.	"	4	.645	.159	.102555	81.	169	5070	253
206	Length.	"	5	.697	.165	.115005	81.	216	6480	324
206	"	"	6	.500	.165	.082500	81.	163	4890	244
206	"	"	7	.807	.164	.132348	81.	205	6150	307
206	"	"	8	.657	.164	.107748	81.	192	5760	288
206	"	"	9	.753	.165	.124245	81.	213	6390	319
206	"	"	10	.663	.167	.110721	80.	196	5880	294
206	"	"	11	.594	.166	.098604	80.	203	6090	304
207	Length.	Aug. 1,	12	.654	.166	.108564	572.5	251	7530	376
207	"	"	13	.674	.167	.112558	580.	248	7440	372
207	"	"	14	.664	.167	.110888	78.	212	6360	318
207	"	"	15	.720	.167	.120240	84.	203	6090	304
207	"	"	16	.666	.167	.111222	573.5	245	7350	367
207	"	"	17	.658	.167	.109886	84.	190	5700	285
207	"	"	18	.730	.166	.121180	84.	230	6900	345
207	"	"	19	.680	.168	.114240	84.	215	6450	322
208	Length.	"	20	.662	.167	.110554	1000. appr.	112	3360	168
208	"	"	21	.725	.162	.117450	84.	215	6450	322

TABLE LII.

and 208, *length strips, from a sheet of English boiler-iron, furnished by*

Effective strain.	Strength in lbs. per square inch.	REMARKS.
6441	52968	Original breadth of the bar about one inch.—Broke at a filed section.
5415	51434	Do.
5187	40163	Do.
4817	46970	This result is probably rather too high, as the weight 169 lbs. broke the bar in a very short time.
6156	53528	Broke at a filed section.
4646	56315	About one-half of the original section was filed away to be sure of escaping the weakening effect of the shears.
5843	44149	The section now filed was obviously not deep enough. In a trial not recorded, a fracture was made entirely out of this filed part.
5472	50786	
6071	48863	The low result is here, probably, to be in part attributed to the deficiency of filing.
5586	50451	
5786	58679	This experiment and No. 2. were certainly made on sections sufficiently filed to test the full strength of the metal.
7154	65897	All the experiments on this bar, (No. 207,) were made at sections more or less filed. It was originally about one inch wide, and .167 inch in thickness. The filing was, in general, confined entirely to the edges, and not extended to the flat surfaces which had been exposed to the rolls.
7068	62794	
6042	54487	
5786	48120	
6983	62786	
5415	49278	
6555	54093	
6128	53641	
3192	28876	Heated by the flame of a spirit lamp applied directly under the bar. Pieces of rolled zinc were melted on the upper surface of the bar before it parted.
6128	52175	

TABLE LIII.

Experiments on bar No. 226. Boiler-plate iron. Manufactured by Messrs. Evan T. Ellicott & Co., of Baltimore. Origin of the metal and mode of manufacture not specified; supposed to be lamellated. *This*

Marks.	Breadth.	Thickness.	Area of measured sections before trial.	No. of the exp't.	DATE.	Area of the section of fracture.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.
0	.763	.244	.186172									
1	.762	.244	.185928		1834.							
2	.761	.240	.182640	1	June 21.	.183026	80.°	315	9450	472	8978	49053
3	.762	.234	.178308									
4	.762	.241	.183642									
5	.760	.241	.183160									
6	.760	.241	.183160	2	"	.181799	80.	351	10530	526	10004	55028
7	.760	.239	.181640									
8	.760	.238	.180880									
9	.760	.240	.182400									
10	.759	.242	.183678	3	"	.177992	1237.	133	3990	199	3791	21298
11	.759	.241	.182919									
12	.762	.242	.184404									
13	.762	.240	.182880	4	June 28.	.183600	73.75	351	10530	526	10004	54488
14	.761	.239	.181879									
15	.760	.238	.180880									
16	.760	.240	.182400									
17	.760	.242	.183920	5	"	.180880	1317.	120	3600	180	3420	18913
18	.756	.239	.180684									
19	.757	.238	.180066									
20	.753	.235	.176955									
21	.757	.233	.176381									
22	.767	.240	.184080									
23	.765	.240	.183600	6	"	.180880	1192.	120	3600	180	3420	18913
24	.765	.240	.183600									
25	.761	.239	.181879									
26	.760	.239	.181640	7	July 2.	.180684	83.	280	8400	420	7980	44165
27	.761	.239	.181879									
28	.766	.237	.181542	8	"	.183109	1245.	133	3990	199	3791	20703
Mean of 29			.182144									
Maximum			.186172	9	"	.183160	1142.	120	3600	180	3420	18672
Minimum			.176381									
Mn. of the 2			.181276	10	July 30.	.181629	80.	275	8250	412	7838	43154
				11	"	.182630	80.	306	9180	459	8721	47752
Diff. of the 2			.009791	12	"	.183425	80.	250	7500	375	7125	38843
				13	"	.181640	80.	285	8550	427	8123	44720
				14	"	.183160	80.	301	9030	451	8579	46839
				15	"	.183522	80.	343	10290	514	9776	53269
				16	"	.180086	80.	370	11100	555	10545	58551
				17	"	.185928	80.	382	11460	573	10887	58555
					Mean of 17	.182185						

TABLE LIII.

strip was cut off in the direction crosswise of the sheet, reduced by filing from 1 *inch in breadth and* $\frac{1}{4}$ *inch thick, to the dimensions given below. Specific gravity*, 7.7428.

Weights producing elongation.	Extension produced.	Point fractured.	REMARKS.
238 245 280 314 315	No perm. elonga. Elonga. decided. 24.86 (wt.off, 24.82) 25.5, gain 1 1-2 in. Broke.	No. 24$\frac{1}{3}$	Began the experiments on this bar by adding weights gradually from 210 lbs., and observing on a length of 24 inches, both when under strain and when relieved, the actual length of that portion. Cold fracture.
		" 25$\frac{1}{3}$	Fracture in the short piece broken off in the first experiment.
		" 19$\frac{2}{3}$	Part heated from 17 to 21. The temp. was twice raised to the point of yielding. After the first trial it was allowed to abate; then raised again and broke the bar. If any variation from the true *breaking heat* existed, it was conjectured to be a trifle too high. But exp't 8 proves it to have been right, (see below.) The iron was distinctly red in day-light.
		" 24	
		" 15	In hot metal from thirteen to sixteen and a half. The temp. having been raised to the point where the bar had begun to yield rapidly, the fire was removed after taking that temp. by the pyrometer. The lever at length ceased to descend, and soon came to rest as the metal cooled. Distinctiy red in day-light. As the bar was sometime strained with this weight, it had probably been so weakened as not again to require the same temperature.
		" 15	Part in metal from thirteen to sixteen and a half. The temp. had not risen so high as in the preceding trial when the bar began again to extend, and finally gave way. The heat was carefully managed by means of the suspended furnace and lever to avoid any excess. Not so red as before,—barely distinguishable in dusk.
		" 18	
		" 10$\frac{3}{4}$	In tin from 8 to 12. This exp't, like the sixth, was made carefully by lowering the fire, when the bar appeared to be stretching too rapidly. Red in day-light.
		" 6	This fracture was doubtless made on a part of the bar which had been originally defective. The section of fracture was much less reduced than in the preceding trial, and was flaky in appearance. *Not visibly red in day-light.*
		" 14$\frac{1}{4}$	
		" 13$\frac{1}{4}$	
		" 10$\frac{1}{3}$	
		" 7	
		" 5$\frac{1}{8}$	
		" 4$\frac{1}{4}$	
		" 3$\frac{1}{3}$	
		" 1	
			The mean area of the 17 sections of fracture is *greater* by .000041 sq. inch, than the mean area of the 29 measured sections.

TABLE LIV.

Experiments on bar No. 227. Manufactured into boiler plate by Messrs. E. T. Ellicott & Co., of Baltimore. The mode of manufacture,

Marks.	Breadth.	Thickness.	Area at the points measured before trial.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temp. Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
0	.765	.235	.179775		1834.						
1	.765	.236	.180540	1	May 31,	.181005	70°	342	10260	513	9747
2	.767	.237	.181779	2	"	.181512	70	349	10470	523	9747
3	.764	.237	.181068								
4	.766	.233	.178478								
5	.766	.232	.177712								
6	.766	.236	.180776	3	June 7,	.180421	1097	174.75	5242.5	262.12	4980.38
7	.767	.235	.180245								
8	.768	.235	.180480								
9	.766	.235	.180010								
10	.764	.235	.179540								
11	.767	.236	.181012								
12	.767	.233	.178711	4	"	.180437	1111	174.75	5242.5	262.12	4980.38
13	.767	.236	.181012								
14	.767	.236	.181012								
15	.769	.236	.181484	5	June 14,	.182035	1187	140	4200	210	3990
16	.769	.238	.183022								
17	.767	.238	.182546								
18	.767	.237	.181779								
19	.767	.239	.183313	6	"	.181632	1155	140	4200	210	3990
20	.768	.236	.181248								
21	.768	.235	.180480								
22	.768	.236	.181248	7	"	.180500	100	348	10440	522	9918
23	.768	.237	.182016								
24	.767	.237	.181779	8	"	.178733	90	397	11910	595	11315
25	.767	.237	.181779	9	June 21,	.180363	75	350	10500	525	9975
26	.767	.237	.181779	10	June 28,	.181897	73.75	291	8730	436	8294
27	.762	.239	.182118	11	"	.181779	73.75	341	10230	511	9719
28	.768	.237	.182016	12	"	.181779	73.75	344	10320	516	9804
				13	"	.181868	73.75	333	9990	499	9491
Mean of 29=			.180997	14	July 2,	.182290	84	288	8640	432	8208
				15	"	.182280	84	300	9000	450	8550
Maximum=			.183313								
Minimum=			.177712		Mn. of 15 =	.181182					
Mn. of the 2			.180512								
Diff. of the 2			.005601								

TABLE LIV.

source of the ore, kind of pig-metal, &c. not specified. Specific gravity, 7.6675. *This bar cut off* crosswise *of the sheet.*

Strength in pounds per square inch.	Point of fracture.	REMARKS.
53849	No. $1\frac{3}{8}$	A short portion only embraced in the space between the wedges.
53699	" $2\frac{3}{8}$	Do. Fracture near the gripe of the wedges. Short piece.
27604	" $7\frac{3}{4}$	Part in melted metal from 6 to $9\frac{1}{2}$. Compound of tin and lead used to float the standard-piece. Mean area of the sections of 7, 8, 9, and $9\frac{1}{2}$ is .180245. In order to ascertain the temperature required to break the bar with half the weight used in the preceding experiment, a calculation was made and this mean area found to require $174\frac{3}{4}$ pounds, which were accordingly applied. The standard piece rose a little way out of the melted metal just before fracture.
27602	" $12\frac{3}{4}$	Part in tin from 11 to 14 inclusive. This experiment was conducted so as to avoid loss, and may be regarded as, on the whole, rather preferable to the preceding in point of accuracy.
21919	" $17\frac{2}{3}$	In melted metal from 17 to 20 inclusive. When the fracture took place the bar had been extending rapidly for some time, and as the furnace was not lowered, would probably have broken with less weight.
21967	" $22\frac{1}{2}$	In metal from 21 to 24. Broke gradually by keeping down the heat and preventing an excess above what was actually necessary to continue the extension of the bar.
54947	" $6\frac{1}{2}$	This temperature was only judged of *approximately* on account of the heat imparted to the machine by the preceding experiment.
63307	" $5\frac{1}{3}$	Machine still warm.
55305	" $8\frac{1}{4}$	
45597	" $23\frac{1}{2}$	
53466	" $24\frac{1}{4}$	
53933	" $25\frac{7}{8}$	
52186	" $15\frac{1}{4}$	
45027	" $18\frac{1}{3}$	This part of the bar appeared very defective from flaws.
46906	" $19\frac{1}{2}$	
		The mean area of the 15 sections of fracture is .000185 square inch *greater* than that of the 29 measured sections.

TABLE LV.

Experiments on bar No. 228. *Manufactured by Messrs. E. T. Ellicott & Co., of Baltimore. The mode of manufacture, source of the ore,*

Marks.	Breadth.	Thickness.	Area of section before trial.	Number of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
0	.762	.243	.185166							
1	.755	.244	.184220							
2	.758	.245	.185710		1834.					
3	.758	.245	.185710	1	Aug 6.	.186528	87°	266	7980	399
4	.762	.245	.186690							
5	.760	.242	.183920							
6	.758	.242	.183436							
7	.760	.246	.186960	2	"	.183436	87	287	8610	430
8	.759	.248	.188232							
9	.758	.248	.187984	3	"	.185710	87	305	9150	457
10	.752	.247	.185744							
11	.754	.244	.183976	4	"	.185710	87	367	11010	550
12	.754	.243	.183222							
13	.760	.243	.184680							
14	.762	.246	.187452	5	"	.187984	87	312	9360	468
15	.761	.247	.187967							
16	.762	.243	.185166							
17	.762	.248	.188976	6	"	.183222	87	317	9510	475
18	.762	.250	.190500							
19	.762	.246	.187452							
20	.755	.247	.186485	7	"	.187967	87	319	9570	478
21	.757	.252	.190764							
22	.754	.252	.190008							
23	.757	.248	.187736	8	"	.190500	87	340	10200	510
24	.757	.248	.187736							
25	.761	.249	.189489	9	"	.184730	85	342	10260	513
26	.760	.249	.189240							
27	.758	.245	.185710	10	"	.187475	85	359	10770	538
28	.754	.245	.184730							
				11	"	.187555	85	361	10830	541
		Mean of 29	.186748							
				12	"	.190008	85	361	10830	541
		Maximum	.190764							
		Minimum	.183222	13	"	.187736	85	363	10890	544
		Mean of these 2	.187493		Mean of 13	.186811				
		Diff. of the 2	.097542							

TABLE LV.

kind of pig-metal, &c. not stated. This bar cut crosswise *of the sheet. Specific gravity*, 7.6675.

Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
7581	40643	No. $13\frac{2}{3}$	The first permanent elongation was taken with a weight of 232 lbs. With 238, the extension was .146 inch on a length of 24 inches; but the recoil .046 when relieved from strain.
8180	44593	" 6	
8693	46809	" 3	
10460	56324	" 2	
8892	47302	" 9	The fracture took place with the weight first applied—the result is therefore supposed to be too high.
9035	49263	" 12	
9092	48370	" 15	Before this fracture was effected, the piece under trial (from 16 to 27,) had become $11\frac{1}{2}$ inches long.
9690	50866	" 18	
9747	52763	" 28	
10232	54578	" $26\frac{1}{2}$	
10289	54859	" $20\frac{1}{4}$	
10289	54150	" 22	
10346	55109	" 23	The mean area of the 13 sections of fracture is .000063 square inch *greater* than that of 29 measured sections.

TABLE LVI.

Experiments on bar No. 229. Boiler plate iron. Manufactured by Messrs. E. T. Ellicott & Co., of Baltimore. Origin of the metal, mode of manufacture, &c., not specified. Supposed to be "lamellated plate."

Marks.	Breadth.	Thickness.	Area of section before trial.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.
0	.766	.238	.182308		1833.							
1	.766	.240	.183840	1	Dec. 28,	.184601	58°	301	9030	451	8579	46473
2	.770	.240	.184800									
3	.765	.241	.184365	2	"	.183840	58	307	9210	460	8750	47595
4	.765	.241	.184365									
5	.760	.243	.184680	3	"	.184560	58	320	9600	480	9120	49415
6	.762	.240	.182880									
7	.763	.240	.183120	4	"	.182960	58	328	9840	492	9348	51093
8	.763	.240	.183120									
9	.762	.235	.179070	5	"	.183120	58	333	9990	499	9491	51283
10	.762	.235	.179070									
11	.758	.235	.178130	6	"	.179070	58	341	10230	511	9719	54275
12	.761	.235	.178835									
13	.764	.235	.179540	7	"	.178130	58	350	10500	525	9975	55997
14	.760	.234	.177840									
15	.760	.234	.177840	8	"	.177840	58	356	10680	534	10146	57028
16	.761	.237	.180357		1834.							
17	.762	.237	.180594	9	Jan. 18,	.186885	1159	168	5040	252	4788	25620
18	.765	.242	.185130									
19	.768	.242	.185856	10	May 31,	.180555	69.5	319	9570	478	9092	50356
20	.767	.245	.187915									
21	.762	.241	.183642	11	"	.185454	70	347	10410	520	9890	53521
22	.764	.235	.179540									
23	.765	.240	.183600	12	"	.186138	70	348	10440	522	9918	53571
24	.767	.243	.186381									
25	.766	.243	.186138	13	"	.186371	70	303	9090	454	8636	46212
26	.766	.243	.186138									
27	.766	.244	.186904	14	"	.185130	70	346	10380	519	9861	53265
27½	.763	.245	.186935									
28	.761	.246	.187206		Mn. of 14=	.183189						
Mean of 30 =			.183338									
Maximum=			.187915									
Minimum=			.177840									
Mean of the 2			.182877									
Diff. of the 2			.010075									

TABLE LVI.

This strip was cut in the direction across the sheet, reduced by filing from one inch in breadth and $\frac{1}{4}$ inch in thickness, to the dimensions given below. Specific gravity 7.7428.

Point of fracture.	REMARKS.
No $4\frac{3}{4}$	The first permanent elongation on this bar was observed under 210 pounds. Part in the machine from 1 to 12.
" 1	
" $1\frac{3}{4}$	
" $6\frac{1}{3}$	A different piece from that broken in the preceding experiment.
" 8	
" $9\frac{7}{8}$	
" 11	
" 14	The 1st, 3d, 5th, 6th, 7th and 8th experiments give a decreasing series of areas with an increasing breaking weight.
" $19\frac{1}{2}$	Part in hot metal from $17\frac{1}{2}$ to $20\frac{1}{2}$, loaded with half the mean weight required in the 8 preceding experiments.
" $22\frac{1}{4}$	
" $23\frac{2}{3}$	
" $25\frac{2}{3}$	
" $19\frac{1}{4}$	Short piece taken off by the wedges.
" 18	
	The mean area of the 14 sections of fracture is .000149 square inch *less* than that of the 30 measured sections.

TABLE LVII.

Experiments on bar No. 230. Manufactured by Messrs. E. T. Ellicott & Co., of Baltimore. The mode of manufacture, the source of the

Marks.	Breadth.	Thickness.	Area of the measured points before trial.	No. of the experim'nt.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight X leverage.	Friction.
0	.760	.250	.190000							
1	.757	.252	.190764							
2	.759	.253	.192027		1834.					
3	.759	.251	.199509	1	June 28.	.190509	82°	330	9900	495
4	.756	.251	.189756							
5	.757	.251	.189907							
6	.755	.254	.191770							
7	.755	.255	.192525	2	"	.190373	82	330	9900	495
8	.753	.255	.192015							
9	.756	.255	.192780	3	"	.192270	82	334	10020	501
10	.755	.254	.191770							
11	.755	.254	.191770	4	"	.192846	82	340	10200	501
12	.755	.254	.191770							
13	.756	.255	.192780	5	"	.191268	82	348	10440	522
14	.758	.255	.193290							
15	.757	.254	.192278	6	"	.192780	82	354	10620	531
16	.757	.254	.192278							
17	.755	.254	.191770	7	"	.192278	82	354	10620	531
18	.757	.254	.192278							
19	.757	.254	.192278	8	"	.191833	82	361	10830	541
20	.755	.254	.191770							
21	.756	.253	.191268	9	"	.192024	82	363	10890	544
22	.756	.251	.189756							
23	.756	.253	.191268							
24	.757	.253	.190521	10	July 8,	.190521	75	404	12120	606
25	.757	.253	.190521							
26	.757	.255	.193035							
27	.757	.254	.192278	11	"	.192784	75	396	11880	594
28	.757	.254	.192278							
29	.757	.253	.190521	12	"	.191770	75	405	12150	607
Mn. of 30 p'ts meas.			.191584	13	"	.191770	75	405	12150	607
		Maximum	.193290	Mean of 13=.191771						
		Minimum	.189756							
		Mn. of these 2	.191523							
		Diff. of the 2	.003534							

TABLE LVII.

ore, the kind of pig-metal, &c. not specified. This bar was cut lengthwise *of the sheet. Specific gravity* 7.6675.

Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
9405	49368	No. 3	First permanent elongation taken with 196 lbs. Under 320 lbs., 26 inches had become 28.1, and after the fracture, the part from 3 to 25 was 24 inches long. When the strain by 317 lbs. was removed the recoil on 24 inches was 1-20 of an inch.
9405	49409	" $5\frac{1}{4}$	The laminæ are now distinctly visible along the edge of the piece broken off, showing marks of *piling* or lamellation.
9519	49508	" $7\frac{1}{2}$	
9699	50294	" $26\frac{1}{4}$	
9918	51849	" 21	After this fracture, the part from 10 to 20 measured 11 inches.
10089	52334	" 9	
10089	52471	" $15\frac{1}{4}$	
10289	53719	" $17\frac{1}{8}$	
10346	53879	" $19\frac{1}{2}$	
11514	60434	" $24\frac{1}{2}$	The piece now under trial, from 21 to $26\frac{1}{3}$, had been exposed to a strain of 386 lbs. for more than ten days, but showed no signs of yielding.
11286	58542	" $14\frac{1}{2}$	This fracture took place almost within the gripe of the wedges.
11543	60192	" 10	
11543	60192	" 12	The mean area of the 13 sections of fracture is *greater* by .000187 square inch than that of the 30 measured sections.

TABLE LVIII.

Comparative table showing the relative advantages of different modes of manufacturing boiler-iron as deduced from preceding tables.

Compar.	Process of manu.	Bars tried at original sections.			Bars tried at deeply filed sections.			Bars reduced to a uniform size by filing.			Names of the Manufacturers.
		No. of the bar.	Strength of each bar.	Mn. st'h. of the sets.	No. of bar.	St'gth of each bar.	Mean strength. of sets.	No. of bar.	Strength of each bar.	Mn. st'h. of the sets.	
1	Piled iron.	2, 4 } 5	52.421		2, 5 }	63.266		3	56.081		Mason & Miltenberger.
		6, 8 }	53.670	53.045			63.266			56.081	
2	Piled.	25	46.079								Shorb.
		27	55.636								
		30	44.703								
		32	52.197								
		35	43.237								
		37	46.155								
		39	40.595								
		41	37.713	45.914							
3	Piled.							226	52.090		Evan T. Ellicott.
								227	53.774		
								228	50.433		
								229	55.774		
								230	54.014	53.217	
4	Piled.	242	59.247	59.017							Valentine & Thomas.
		243	58.787								
5	Ham-mer'd plate.				9	67.211		14	57.840		Spang & Son.
		9	58.243		10	64.511		16	56.891		
		11	46.126		11	55.529					
		17	44.249		13	50.908					
		18	50.218		15	50.166					
		21	39.578		22	59.372					
		23	44.289	47.117	23	62.646	58.620			57.365	
6	Ham-mer'd plate.	78	43.006		75	60.433		88	53.803		Schoenberger.
		81	51.318		83	56.046					
		83	49.239		85	60.440					
		84	45.443		86	62.156					
		85	51.606		90	52.301					
		87	51.287								
		90	43.365	47.895			58.275			53.803	
7	Ham-mer'd plate.	46, 48 }	59.904					49	59.607		Blake.
		51	61.091								
		53	56.477								
		68	61.127								
		70	47.638								
		71	64.823								
		73	52.657	57.676						59.607	
8	Pud-dled iron.	42	52.413		56	58.964		74	51.039		Blake.
		44	54.718		58	70.938					
		56	57.926		60	60.907					
		58	53.112		62	58.376					
		59	48.308		65	62.917					
		61	55.904								
		64	45.092								
		65	51.255	52.341			62.420			51.039	

Strength of Boiler Iron Manufactured by Different Processes.

In making a comparison for determining this point, it was necessary to distinguish those experiments which were made on the strips as they came from the shears, from those which were performed on deeply filed sections, as well as from those in which the bars had been reduced to a uniform size.

It is proper to observe, that the inherent irregularities of the metal, even in the best specimens, whether of rolled or hammered iron, seldom fall short of 10 or 15 per cent., of the mean strength.

Thus, of the bars referred to in the preceding table, No. 22 exhibits an irregularity of 19 $\frac{2}{10}$ per cent.; No. 23, 29 $\frac{3}{10}$, No. 90, 24; No. 230, 20 $\frac{8}{10}$, and No, 228, 31 per cent. of the mean strength. These two last mentioned bars had been reduced to an uniform size and were entirely broken up at ordinary temperatures, chiefly with a view to the degree of uniformity of strength.

It will be seen, on inspecting the preceding table, that of all the kinds of iron here presented, the piled iron of Mr. Shorb proved most defective in strength; some specimens of that kind, exhibiting, but little more than half as much tenacity as the best boiler iron which came under examination. Nos. 39, and 41, in particular, were found to possess extensive unwelded portions between the several laminæ of the plate.

These developed themselves to the distance of several inches when subjected to the action of the machine.

In comparing the two kinds of iron manufactured by Messrs. Blake & Co. we find that the kind produced from blooms, and denominated hammered plate, is superior by about 13 per cent. to that manufactured by puddling.

It will be observed that of the eight sets of results embraced in table LVIII., four, viz.: Nos. 1, 5, 6, and 8 afford the means of comparing together those trials which were made after all the three modes of preparing the bars.

No. 1 gives to the rough bars a strength of 53045; to that which was reduced to uniform size, 56081, and to those filed in notches on the edges, 63266. In a similar manner finding for the other three sets their mean results, we have for bars tried as they came from the shears, mean of four sets, 50099 lbs; reduced to uniform size, 54572; for those filed on the edges, 60645.

Strength of iron made by other processes than rolling into plates.

The tables numbered from LIX. to LXXVIII. inclusive, will be found to contain the results of experiments on various specimens of iron manufactured by other processes than rolling into boiler-plate, particularly those of hammering into bars, slitting into rods, rolling into bolts and drawing into wires.

In the number of specimens here tried the committee have included a few of foreign iron, Russian, Swedish and English, as well with a view to compare the results of their method of trial with those of former experimenters, as to show how far the processes generally adopted in manufacturing the article in this country may admit of improvement.

A few experiments on boiler-iron, made upon original or on filed sections, will be found in Table LIX., and a small number of trials on cast iron, which does not, however, appear to have been of a very favourable character. Table LX. also contains accounts of a miscellaneous collection of specimens obtained from different quarters. The remaining tables in this series relate to bars which had been reduced to approximate uniformity of size throughout their whole length, and not a few of them were tried at elevated as well as ordinary temperatures; but of the former we shall speak more at length in a subsequent part of this report.

TABLE LIX.

Experiments on bars No. 99, 101, 103, 105, 180, 181, 182 and 185. The first two manufactured by Pennock into boiler plate; the next two by Jackson into the same article, and the remaining numbers obtained from

No. of the bar.	Direction of the slit.	No. of the exp.	DATE.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temp. Fah.	Breaking wht. in the scale.	Breaking wht. X leverage.	Friction.	Effective strain.	Strength in lbs. per sq. inch.
			1832.										
99	Cross.	1		24.3	1.016	.214	.217424	62.25	378	11340	567	10773	49548
101	L'gth.	2		25.1	1.014	.230	.233220	62.5	403	12090	604	11486	49258
101	"	3			.826	.240	.198240	62.5	384	11520	576	10944	55206
103	Cross.	4		23.8	1.038	.190	.197220	62.25	321	9630	481	9149	41319
103	"	5	May 30,	9.6	.984	.200	.196800	67.	361	10830	541	10289	52281
105	L'gth.	6	Ap. 28,	24.2	1.050	.196	.205800	62.5	322	9660	483	9177	44591
105	"	7			1.045	.196	.204820	62.5	345	10350	517	9833	48068
On a bar of slit iron hammered out, having two sections much smaller than the rest but equal to each													
180	Hammered and upset.	8		10.25	.882	.216	.190512	60.	324	9720	486	9234	48469
On a bar of cast steel furnished by Mr. R. Tyler in which were two equal square sections. 31 of an inch													
181	Cast steel.	9			.310	.310	.096100	65.	441	13230	661	12569	130681
On a bar of iron furnished by Mr. Super, manufactured by Washington Jackson, rolled and slit.													
182	Rolled & slit.	10		23.5	.980	.254	.248920	65.	455	13650	682	12968	52096
On a bar of cast iron obtained from the foundry of Messrs. Levi Morris & Co. Philadelphia.													
185	Cast iron.	11		24.	1.032	.280	.288960	69.	196	5880	294	5586	19337
185		12		19.2	1.054	.280	.295120	69.	210	6300	315	5985	20279
185		13			1.056	.250	.264000	69.	212	6360	318	6042	22886

TABLE LIX.

different quarters, as specified below. Specific gravities not taken.

Weights producing temporary elongation.	Elasticity of the bar.	Length after trial.	Area of the section after trial.	REMARKS.
224 336 378 378	20′ 36 42 Broke.	24.45	1.010×.204 =.206040	Broke under 378 lbs. after the elasticity had been observed. Gave way suddenly. A small scale or flaw appeared on one side of the section of fracture.
224 336 403	35 41 Broke.	25.3	.986×.210 =.207060 .821×.196 =.160916	Broke at the filed section.
224 280 308 321	38 34 43.5 Broke.	24.09	1.014×.174 ×.176436	
168 361	07. Broke.	9.8	.942×.152 =.143184	
224 294 320 322	1.03 1.04 1.03 Broke.	24.45*	1.024×.180 =.184320	Broke near the wedges. * The length after fracture is that of the whole bar after both trials.
other; the one upset--the other not. Furnished by Mr. Rufus Tyler.				
		10.86		Direct measurements were taken to ascertain the recoil of the bar when relieved from strain under different whts. With 224 lbs. the length was 10.40 when the weight was applied; but only 10.366 when it was taken off.—With 250 lbs. it was 10.50 and 10.45 in the two cases; and with 273 lbs. 10.62 and 10.60. Broke at the section *not upset.*
on a side, the one upset—the other not.				
112 224 336 385 406 415 422 429 441	20.5 30. 28. 36.5 40.5 39.5 36.5 37.5 Broke.		.840×.190 =.159600	Broke at the *upset* part.
		25.66		
168 196	37 Broke.			A filed section was made;–its area 1.018 × .230=.234140. Broke suddenly with the weight recorded—filed section not broken.
189 210	35 Broke.			Do. It was found difficult to make the wedges hold the cast bars so as to equalize the strain. The filed section remains unbroken and has of course borne 25.762 lbs. to the sq. inch.

TABLE LX.

Experiments on a variety of specimens of iron, furnished by different

No. of the bar.	Mode of manufacture.	DATE.	No. of the exp't.	Length before trial.	Breadth.	Thickness.	Area of the section of fracture before trial.	Temp. Fah.	Breaking weight in the scale.	Breaking weight X leverage.	Friction.	Effective strain.
On a bar furnished by Mr. R. Tyler, in which was a section annealed at a												
191	Ham. & annealed.		1	15.	.880	.220	.193600	68	326	9780	489	9291
On a small railroad bar of English "common iron," in which a deep section had Furnished by Gerard Ralston, Esq. of Philadelphia.												
215	Rolled into rail.		2		.740	.262	.193880	81	412	12360	618	11742
On a rod of round iron made from the pig, by puddling, piling, and then rolling,												
217	Puddled, pil. & rol.		3		Diam. .660	Diam. .660	.342120	68	700	21000	1050	19950
On specimens of Juniata iron, both *hammered* and *slit*. Furnished by Mr. G.												
234	Hamm'd.	1833. May 18,	4		.357	.357	.127449	77	254	7620	381	7239
234	"	"	5		.300	.382	.114600	77	209	6270	313	5959
234	"	"	6		.368	.382	.140576	77	273	8190	409	7781
235	Rolled & slit.	"	7		.300	.295	.088500	77	196	5880	294	5586
On a small bar furnished by Messrs. Yeatman & Woods, of Nashville, Tenn.												
236	Rolled.	"	8		.324	.392	.127008	77	231	6930	346	6584
On a bar of rolled and slit iron, manufactured with coke, and reduced by pud- Susquehanna, Pa.												
244	Rolled & slit.	1836. Mar. 21.	9	4.5	.337	.253	.085261	50	209	6270	313.5	5856.5

TABLE LX.

individuals, as mentioned below. Specific gravity not taken.

Strength in lbs. per square inch.	Length after trial.	Area of section after trial.	REMARKS.
welding heat.			
47991	16.42	.766×.156 =.119496	Broke at the annealed part. Began to be permanently elongated with 210 lbs. and continued to extend with the successive additions of weight until broken.
been filed, the bar being originally an inch wide and one-third of an inch thick.			
60563			This section was so deeply filed as to remove all probability of a defect in the *remaining* section.
without any other operation for refining the metal. Furnished by Jonah Thompson, Esq.			
58313			
Valentine, of Centre county, Pennsylvania.			
56799			
51981			
55351			
63119			
51839			
dling. Furnished by Peter Ritner, Esq., Carthause's place, West Branch of the			
68689			Fracture granular, with much crystalline structure. A yellowish tinge perceptible in certain parts.

TABLE LXI

Experiments on bars No. 212 and 213, drawn out of a specimen of English bolt iron $1\frac{1}{8}$ inches in diameter, presented by G. Ralston, Esq., described as, "E. V. best patent cable bolt iron." The specimen had been formed into a knot when cold, by means of a pair of pincers. The

Marks. Bar 213.	Breadth.	Thickness.	Area of the sections measured before trial.	No. of the experiment.	DATE.	Area at the section of fracture.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.
1	.741	.239	.177099		1833.							
2	.743	.236	.175348	1	July 20,	.175171	56°	364	10920	546	10374	59222
3	.743	.236	.175348									
4	.743	.236	.175348	2	"	.175348	80	366	10980	549	10431	59487
5	.742	.236	.175112									
6	.743	.236	.175348	3	July 25,	.175348	84	410	12300	615	11685	66639
7	.743	.235	.174605									
8	.744	.235	.174840	4	"	.174976	80	436	13080	654	12426	71015
9	.742	.236	.175112									
10	.744	.236	.175584	5	"	.174859	78	439	13170	658	12512	71555
11	.744	.236	.175584									
12	.744	.236	.175584	6	"	.175128	78	437	13110	655	12455	71119
13	.744	.239	.177816									
14	.741	.238	.176358	7	"	.173628	78	437	13110	655	12455	71734
15	.742	.237	.175854									
16	.741	.237	.175617	8	"	.177162	78	437	13110	655	12455	70303
17	.743	.238	.176834									
18	.740	.236	.174640	9	"	.175617	78.5	437	13110	655	12455	70921
19	.740	.236	.174640									
20	.744	.239	.177816	10	"	.175434	78.	435	13050	652	12398	70670
21	.742	.237	.175854									
22	.742	.234	.173628	11	"	.175795	77.5	436	13080	654	12426	70685
23	.742	.235	.174370									
24	.743	.236	.175348	12	"	.176358	78.	439	13170	658	12512	70947
25	.740	.236	.174640									
26	.741	.237	.175617	13	"	.175584	78.	439	13170	658	12512	71265
27	.741	.236	.174876									
					Mn. of 13 =	.175416						
Mean of 27=			.175512	Experiment on No. 212, part of the same bolt.								
Maximum			.177816	Br.	Th.							
Minimum			.173628	1.041	.256	.268496	82	565	16950	847	16103	59975
Mean of the 2			.175722									
Diff. of the 2			.004188									

TABLE LXI.

exterior dimensions of the knot were $5\frac{1}{8}$ *by* $3\frac{1}{8}$ *inches. After heating and untieing this knot the bar was drawn out by the hammer. No.* 213 *was reduced to a nearly uniform size by filing, and then gauged at every inch, from* 1 *to* 27 *inches. No.* 212 *tried at a filed section. Sp. grav.* 7.6897.

Point of fracture.	REMARKS.
No. $4\frac{3}{4}$	Part in tin from 5 to 8. The influence of the heat at this temperature was made to extend to all parts of the bar—with a view to ascertain whether any points of inferior strength could be thereby detected—but the structure appears to have been remarkably uniform, as seen in subsequent trials.
" 3	
" $9\frac{1}{2}$	
" $6\frac{1}{2}$	
" $23\frac{1}{2}$	
" $25\frac{1}{2}$	
" 22	
" $20\frac{1}{3}$	
" 16	
" $19\frac{1}{4}$	
" $15\frac{1}{4}$	
" 14	
" 12	
	The mean area of the 13 sections of fracture is .000096 square inch *less* than the mean area of the 27 measured sections.
	This fracture made on a filed section.

TABLE LXII.

Experiments on bar No. 214, drawn out of a specimen (the same with 213) of English cable bolt iron, $1\frac{1}{8}$ inches in diameter, presented by G. Ralston, Esq., described as "E. V. best patent cable bolt iron." The

Marks.	Breadth.	Thickness.	Area of section at the points measured.	DATE.	No. of the experiment.	Area of the section of fracture before trial.	Temperature. Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.
1	.752	.239	.179728	1833.								
2	.751	.237	.177987	July 27,	1	.177750	83°	354	10620	531	10089	56759
3	.750	.237	.177750									
4	.750	.237	.177750									
5	.750	.239	.179250	"	2	.178066	83	370	11100	555	10545	59219
6	.750	.239	.179250									
7	.750	.239	.179250									
8	.749	.239	.179011									
9	.750	.241	.180750									
10	.749	.341	.180509									
11	.749	.241	.180509	"	3	.180509	824 / 814	354	10620	531	10089	55892
12	.749	.241	.180509									
13	.749	.239	.179011									
14	.747	.238	.177786									
15	.752	.239	.179728	"	4	.179250	81	408	12240	612	11628	64870
16	.751	.240	.180240									
17	.750	.239	.179250	"	5	.180690	82	434	13020	651	12369	68454
18	.749	.239	.179011									
19	.748	.240	.179520									
20	.750	.239	.179250	"	6	.179130	932	283	8490	424	8066	45029
21	.750	.240	.180000									
22	.748	.241	.180268									
23	.749	.240	.179760									
24	.749	.240	.179760									
25	.752	.240	.180480	"	7	.179760	1022	236	7080	354	6726	37410
26	.752	.241	.181232									
27	.752	.238	.178976									
Mean of 27			.179501	Aug. 1,	8	.179760	80	294	8820	441	8379	46612
Maximum			.181232	"	9	.180141	80	383	11490	574	10916	60597
Minimum			.177750	"	10	.179393	80	383	11490	574	10916	60850
				"	11	.180240	80	362	10860	543	10317	57240
Mn. of these 2			.179491	"	12	.180856	80	380	11400	570	10830	59882
				"	13	.179745	80	377	11310	565	10745	59779
Diff. of the 2			.003482	"	14	.180069	80	392	11760	588	11172	62043
				"	15	.178092	80	401	12030	601	11429	64175
				Mean of 15		.179563						

TABLE LXII.

bar reduced by hammering and filing to uniform size, and then gauged at every inch from 1 *to* 27. *Specific gravity*, 7.6897.

Breadth after trial.	Thickness after trial.	Area after trial.	Point of fracture.	REMARKS.
			No. $3\frac{2}{3}$	
			" $2\frac{1}{3}$	Short piece broken off in the preceding experiment. These two experiments were made on the bar when *cold*, with a view to get the approximate tenacity in that state.
.623	.196	.122108	" $10\frac{1}{2}$	Having placed in the scale the same weight as was used in the first experiment, the temperature was raised, by means of the moveable furnace, to such a point that the bar was rapidly giving way. The standard piece was withdrawn and tried twice, giving, successively, the temperatures marked.
			" $6\frac{1}{4}$	Part now in the machine from $3\frac{2}{3}$ to $10\frac{1}{2}$
			" $9\frac{1}{4}$	Same part under trial as in the preceding exp't.
.563	.174	.099651	" $17\frac{1}{2}$	The scale was now loaded with four-fifths of the breaking weight in the first experiment. The difference of areas caused an excess of 452 lbs. above four-fifths of the strength exhibited in that experiment. Bar not actually parted.
.603	.185	.111555	" $23\frac{2}{3}$	Part in tin from 22 to 25. The weight employed $\frac{2}{3}$ of that used in the first experiment. Section larger, hence the strength is 978 lbs. less than $\frac{2}{3}$ of 56759. The length from 23 to 24 was now 1.46 in. Not actually parted.
			" $23\frac{2}{3}$	The same section as that tried in the preceding experiment.
			" $22\frac{1}{4}$	
			" $18\frac{3}{4}$	
			" $24\frac{2}{3}$	
			" $25\frac{1}{2}$	
			" $16\frac{1}{2}$	
			" $15\frac{2}{3}$	
			" $13\frac{3}{4}$	
				The mean area of 15 sections of fracture is .000062 square inch *greater* than the mean area of the 27 measured sections.

TABLE LXIII.

Experiments on bars No. 213a and 214a, taken respectively from bars 213 and 214. Reduced by hammering and filing to a nearly uniform

Marks.	Breadth.	Thickness.	Area before trial at the points measured.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
		213*a*									
1	.748	.230	.172040								
2	.746	.230	.171580	1		.171580	78	396	11880	594	11286
3	.747	.232	.173304								
4	.747	.229	.171063								
5	.747	.229	.171063	2		.170949	78	421	12630	631	11999
6	.745	.229	.170605								
7	.745	.230	.171350								
8	.745	.230	.171350	3		.170605	78	431	12930	646	12284
9	.745	.230	.171350								
Mean of 9			.171534	4		.170977	78	431	12930	646	12284
Maximum			.173304		Mn. of 4 =	.171028					
Minimum			.170605								
Mn. of the 2			.171954								
Diff. of the 2			.002699								
		214*a*									
1	.750	.226	.169500								
2	.747	.225	.168075	1		.169231	80	410	12300	615	11685
3	.743	.225	.167175								
4	.743	.228	.169404								
5	.744	.228	.169632	2		.169518	80	412	12360	618	11742
6	.739	.226	.167014								
7	.739	.227	.167753								
8	.739	.227	.167753	3		.168246	84	443	13290	664	12626
9	.739	.229	.169231								
10	.739	.228	.168492								
				4		.168966	84	438	13140	657	12483
Mean of 10			.168402								
Maximum			.169632		Mn. of 4 =	.168990					
Minimum			.167014								
Mn. of these 2			.168323								
Diff. of the 2			.002618								

TABLE LXIII.

{ *size, and then gauged at every inch. These bars were both hammered until cold, technically "hammer-hardened."*

Strength in lbs. per sq. inch.	Point of fracture.	REMARKS.
65718	No. 2	
70190	" $5\frac{1}{4}$	
72002	" 6	
71845	" $6\frac{1}{2}$	The mean area of these 4 sections of fracture is .000506 square inch *less* than the mean area of the 9 measured sections.
69047	" 9	
69267	" $4\frac{1}{2}$	
75045	" $8\frac{1}{3}$	
73879	" $1\frac{3}{8}$	The mean area of these 4 sections of fracture is .000498 square inch *greater* than the mean area of the 10 measured sections.

TABLE LXIV.

Experiments on a specimen of iron wire. Manufactured at Phil-process of manufacture, refining, &c. not stated.

No. of the bar.	Mode of manufacture.	DATE.	Number of the experiment.	Diameter before trial.	Area of section before trial.	Temperature. Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
199	Wiredrawn.		1	.333	.0870922	550°	246	7380	369
199	"		2	.333	"	66	253	7590	379
199	"		3	.333	"	66	257	7710	385
199	"		4	.333	"	66	257	7710	385
199	"		5	.333	"	66	257	7710	385
199	"		6	.333	"	60	258	7740	387
199	"		7	.333	"	50	270	8100	405
199	"		3	.333	"	50	221	6630	331
199	"		9	.333	"	60	236	7080	354
199	"		10	.333	"	450	242	7260	363
199	"		11	.333	"	60	249	7470	373
199	"		12	.333	"	60	241	7230	361
199	"		13	.333	"	60	243	7290	364

TABLE LXIV.

lipsburg, Pennsylvania, by Mr. Hardman Phillips, from Juniata iron,

Effective strain.	Strength in lbs. per square inch.	Area of section after trial.	REMARKS.
			The specific gravity of this wire was 7.7272.
7011	80501		
7211	82797	$.240 \times .240 \times .7854 = .045239$	Only two measurements of area after fracture are recorded, but others were occasionally taken, all agreeing very nearly with these, and exhibiting a uniform diminution in all directions, and a remaining section almost precisely one-half as great as the original transverse section of the wire.
7325	84106		
7325	84106		
7325	84106		
7353	84427		
7695	88354		
6299	72325		
6726	77228		
6897	79192		
7097	81488		
6869	78870	$.234 \times .234 \times .7854 = .0430132$	
6926	79524		

TABLE LXV.

Experiments on bar No. 223 A. From Missouri. Manufactured by Mr. Massey, at the Maramec Iron Works. Drawn under the hammer

Marks.	Breadth.	Thickness.	Area of sections measured before trial.	No. of the experiment.	DATE.	Area of section at the point of fracture before trial.	Temp. Fah.	Breaking wht. in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per sq. inch.
0	.761	.230	.175030		1833.							
1	.758	.230	.174340	1	May 2,	.175180	80	269	8070	403	7667	43766
2	.758	.232	.175856									
3	.758	.230	.174340	2	"	.174685	80	281	8430	421	8009	45896
4	.758	.230	.174340									
5	.756	.230	.173880	3	"	.174867	79.5	281	8430	421	8009	45556
6	.757	.231	.174862									
7	.758	.231	.175098	4	"	.175972	79.5	281	8430	421	8009	45513
8	.756	.232	.175392									
9	.759	.232	.176088	5	"	.175098	79.5	294	8820	441	8379	47853
10	.758	.232	.175856		1834.							
11	.759	.232	.176088	6	May 4,	.175307	570	309	9270	463	8807	50238
12	.760	.232	.176320									
13	.760	.231	.175560									
14	.760	.230	.174800	7	"	.174845	578	328	9840	492	9348	53465
15	.760	.232	.176320									
16	.759	.231	.175329									
17	.759	.229	.173811	8	"	.174665	65	363	10890	544	10346	59233
18	.759	.230	.174570									
19	.758	.232	.175856									
20	.758	.230	.174340	9	"	.173250	65	354	10620	531	10089	58239
21	.758	.231	.175098									
22	.758	.232	.175856									
23	.758	.232	.175856	10	"	.175856	65	358	10740	537	10203	58018
24	.758	.232	.175856									
25	.756	.232	.175392	11	"	.175477	65	358	10740	537	10203	58144
26	.755	.231	.174405									
$26\frac{1}{3}$	.750	.231	.173250		Mn. of 14 =	.175018						
Mean of 28			.175135									
Maximum			.176320									
Minimum			.173250									
Mean of the 2			.174785									
Diff. of the 2			.003070									

TABLE LXV.

and then reduced by filing and gauged at points 1 *inch apart. Specific gravity* 7.7708.

Weight producing elongation.	Increase of length in 24 inches.	Point fractured.	REMARKS.
168 224 252 269	1st permanent. . 3 inch. . 7 do. Broke.	No. $13\frac{1}{2}$	
		" $0\frac{1}{2}$	
		" 6	Weights not altered.
		" $9\frac{1}{2}$	Do.
		" $2\frac{1}{2}$	
		" $14\frac{1}{3}$	Part in tin from 18 to 22.
		" $19\frac{2}{3}$	Broke in the melted tin—part in the metal, same as in the preceding experiment.
		" $18\frac{2}{3}$	
		" $26\frac{3}{16}$	A different piece from the preceding—had been most remote from the melted metal, fracture diagonal.
		" $23\frac{3}{4}$	Had not been in tin.
		" $21\frac{1}{2}$	A flaw about the middle of the thickness now appeared.—This bar exhibited more than any yet tried, a dull recoil only, when it finally gave way, as if the elasticity had been almost totally destroyed. The mean area of the 11 sections of fracture is .000117 square inch *less* than that of the 28 measured sections.

TABLE LXVI.

Experiments on bar No. 223 B. From Missouri. Manufactured by Mr. Massey, at the Maramec Iron Works, drawn under the hammer,

Marks.	Breadth.	Thickness.	Area of section at the points measured before trial.	DATE.	No. of the exp't.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
1	.764	.239	.182596								
2	.755	.240	.181200								
3	.755	.240	.181200								
4	.755	.239	.180445	1833.							
5	.755	.238	.179690	May 9,	1	.179690	76	262	7860	393	7467
6	.755	.239	.180445								
7	.755	.238	.179690								
8	.755	.236	.178180								
9	.752	.236	.177472								
10	.753	.236	.177708								
11	.753	.238	.179214	"	2	.181041	76	270	8100	405	7695
12	.755	.239	.180445								
13	.755	.238	.179690	"	3	.179172	76	271	8130	406	7724
14	.755	.239	.180445								
15	.755	.239	.180445	"	4	.180960	76	277	8310	415	7895
16	.755	.240	.181200								
17	.755	.239	.180445	"	5	.181200	76	284	8520	426	8094
18	.755	.240	.181200								
19	.756	.238	.179928	"	6	.180445	76	284	8520	426	8094
20	.756	.237	.179172	1833.							
21	.756	.239	.180684	May 11,	7	.178180	576	313	9390	469	8921
22	.755	.240	.181200								
23	.755	.240	.181200	"	8	.180445	70.5	336	10080	504	9576
24	.753	.240	.180720								
25	.755	.240	.181200	"	9	.182596	70.5	322	9660	483	9177
26	.755	.240	.181200								
27	.760	.240	.182400	"	10	.180067	70.5	347	10410	520	9890
27¼	.762	.240	.182880								
				"	11	.179690	70.5	347	10410	520	9890
Mean of 28 =			.180439								
				Mean of 11		.180317					
Maximum =			.182880								
Minimum =			.177472								
Mn. of these 2			.180176								
Diff. of the 2			.005408								

TABLE LXVI.

reduced by filing, and gauged at points one inch apart. Specific gravity, 7.6742.

Strength in lbs. per square inch.	Point fractured.	REMARKS.
41555	No. 13	Under a weight of 245 lbs. in the scale the elongation had become .85 inch in 22 inches. The breadth at No. 13 was then .718, diminution .037. After this experiment 12 inches on one side of the fracture, as originally measured, were found to have been elongated to 13½, and 10 on the other to 11 1-20, exhibiting an extension of 2.55 in 22 inches.
42504	" 18⅛	
43109	" 20	
43628	" 23½	
44669	" 25½	
44855	" 14⅝	
50068	" 8	Part in tin from 6½ to 10.
53069	" 12	Part now under trial from 8 to 13.
50258	" 1	Broke soon after applying the weight. Part now under trial from 1 to 8.
54924	" 6½	Broke quickly with this weight.
55039	" 5	
		The mean area of the 11 sections of fracture is .000122 sq. inch *less* than the mean area of the 28 measured sections.

TABLE LXVII.

Experiments on bar No. 223 C. Manufactured at the Maramec Iron Works, Missouri, by Mr. Massey, drawn under the hammer, re-

Marks.	Breadth.	Thickness.	Area before trial.	No. of the exp't.	DATE.	Areas of section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
1	.741	.243	.180063		1833.						
3	.751	.242	.181743	1	May 11,	.180870	576°	282	8460	423	8037
2	.748	.242	.181016								
4	.751	.242	.181742	2	"	.181232	578	308	9240	462	8778
5	.751	.242	.181742								
6	.751	.240	.180240	3	"	.182178	578	329	9870	493	9377
7	.751	.241	.180991								
3	.751	.242	.181742	4	May 16,	.181742	550	338	10140	507	9633
9	.751	.240	.180240								
10	.751	.240	.180240	5	"	.180870	550	331	9930	496	9434
11	.751	.242	.181742								
12	.751	.242	.181742	6	"	.179545	78	364	10920	546	10374
13	.751	.242	.181742								
14	.751	.242	.181742	7	"	.179301	78	365	10950	547	10403
15	.751	.242	.181742								
16	.751	.243	.182493	8	"	.178738	78	371	11130	556	10574
17	.752	.241	.181232								
18	.752	.241	.181232	9	"	.180991	78	372	11160	558	10602
19	.751	.241	.180991								
20	.749	.241	.180509	10	May 18,	.181742	78	369	11070	553	10517
21	.752	.241	.181232								
22	.751	.239	.179489	11	"	.181379	78	369	11070	553	10517
23	.751	.238	.178738								
24	.750	.242	.181500	12	"	.181492	78	369	11070	553	10517
25	.751	.241	.180991								
26	.751	.241	.180991	13	"	.181742	78	371	11130	556	10574
27	.748	.242	.181016								
27.25	.745	.241	.179545	14	"	.181742	78	371	11130	556	10574
		Mean of 28	.181015		Mean of 14	.180968					
		Maximum	.182493								
		Minimum	.178738								
		Mean of the 2	.180615								
		Differ. of the 2	.003755								

TABLE LXVII.

duced by filing, and gauged at every inch. Specific gravity 7.7708.

Strength in lbs. per square inch.	Point of fracture.	REMARKS.
44435	No. 20½	The whole length of the bar was put under trial. The part in tin from 5½ to 9.
48435	" 18	Same part in tin as above.
51713	" 16¼	Same part in tin. This fracture is at the largest section in the bar.
53004	" 2	The same part still in tin.
52158	" 21½	Part in tin from 22 to 26. Broke at a place previously in the gripe of the wedges.
57779	" $27\frac{2}{10}$	
58020	" 22¼	
59159	" 23	
58577	" 25⅓	
57879	" 13¼	
57983	" 2½	
57947	" 7⅔	
58181	" 11	
58181	" 4	
		The mean area of the 14 sections of fracture is .000047 square inch *less* than that of the 28 measured sections.

TABLE LXVIII.

Experiments on bar No. 223 D. From Missouri. Manufactured by Mr. Massey, at the Maramec Iron Works, drawn under the hammer

Marks.	Breadth	Thickness.	Areas at the points gauged.	No. of the experiment.	DATE.	Area at the point of fracture.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
1	.755	.242	.182710								
2	.754	.241	.181714		1833.						
3	.753	.242	.182226	1	May 30,	.182226	72°	275	8250	412	7838
4	.752	.242	.181984								
5	.752	.242	.181984								
6	.752	.242	.181984	2	"	.183407	68	357	10710	535	10175
7	.752	.242	.181984								
8	.752	.242	.181984								
9	.752	.242	.181984	3	"	.182602	68	368	11040	552	10488
10	.752	.242	.181984								
11	.753	.241	.181473								
12	.753	.242	.182226	4	"	.182736	68	368	11040	552	10488
13	.753	.242	.182226								
14	.753	.242	.182226								
15	.753	.242	.182226	5	"	·182226	528	347	10410	520	9890
16	.753	.242	.182226								
17	.753	.241	.181473								
18	.753	.242	.182226	6	"	.181849	69.5	336	10080	504	9576
19	.753	.242	.182226								
20	.753	.242	.182226								
21	.753	.243	.182976	7	June 1,	.181984	73.	375	11250	562	10688
22	.753	.243	.182979								
23	.752	.243	.182736								
24	.752	.244	.183488	8	"	.182226	73.	376	11280	564	10716
25	.752	.245	.184240								
26	.751	.244	.183244								
27	.752	.244	.183488	9	"	.181749	73.25	380	11400	570	10830
Mean of 27			.182387								
				10	"	.182710	73.5	348	10440	522	9918
Maximum			.184240								
Minimum			.181473								
				11	"	.181984	73.5	357	10710	535	10175
Mn. of the 2			.182856								
Diff. of the 2			.002767		Mean of 11	.182236					

TABLE LXVIII.

and reduced by filing. Gauged at points from 1 *to* 27 *inches. Specific gravity* 7.7708.

Strength in pounds per square inch.	Point of fracture.	REMARKS.
43012	No. 19	The whole bar in the machine.
55477	" $26\frac{2}{3}$	Part now in from 19 to 27.
57436	" $20\frac{1}{2}$	
57394	" 23	
54273	" $14\frac{3}{4}$	Part now in the machine from 4 to 19—in tin from $9\frac{1}{2}$ to 13.
52657	" $16\frac{1}{2}$	
58730	" $9\frac{1}{4}$	
58807	" $14\frac{1}{2}$	Broke within the wedges.
59593	" $11\frac{1}{3}$	Broke at a part which had been heated.
54283	" 1	Piece now in has not been tried before.
55911	" 4	The mean area of the 11 sections of fracture is .000151 square inch *less* than that of the 27 measured sections.

TABLE LXIX.

Experiments on bar No. 223 E. From Missouri. Manufactured by Mr. Massey, at the Maramec Iron Works. Drawn under the ham-

Marks.	Breadth.	Thickness.	Areas of section at the points measured before trial.	No. of the experim't.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
1	.742	.242	.179564								
2	.741	.240	.177840								
3	.742	.236	.175112		1833.						
4	.740	.238	.176120	1	June 6,	.178055	550° 71	280	8400	420	7980
5	.742	.237	.175854								
6	.740	.240	.177600								
7	.740	.240	.177600								
8	.740	.241	.178340	2	"	.176001	71	298	8940	447	8493
9	.741	.241	.178581								
10	.741	.241	.178581	3	"	.176365	71	301	9030	451	8579
11	.740	.239	.176860								
12	.741	.240	.177840	4	"	.177186	71	301	9030	451	8579
13	.741	.239	.177099								
14	.741	.239	.177099	5	"	.177915	71	310	9300	465	8835
15	.741	.239	.177099								
16	.741	.239	.177099	6	"	.177170	71	310	9300	465	8835
17	.740	.238	.176120								
18	.740	.240	.177600	7	"	.178270	71	305	9150	457	8693
19	.740	.240	.177600								
20	.740	.239	.176860	8	June 13,	.177099	71	312	9360	468	8892
21	.740	.238	.176120								
22	.740	.239	.176860	9	"	.178007	71	312	9360	468	8892
23	.740	.240	.177600								
24	.741	.238	.176358	10	"	.178370	71	320	9600	480	9120
25	.741	.238	.176358								
26	.738	.238	.175644	11	"	.177600	71	320	9600	480	9120
27	.738	.239	.176382								
27.3	.745	.239	.178055	12	"	.175616	71	320	9600	480	9120
		Mean of 28	.177137		Mean of 12	.177304					
		Maximum	.179564								
		Minimum	.175112								
		Mean of these 2	.177338								
		Diff. of the 2	.004452								

TABLE LXIX.

mer, reduced by filing, and gauged at points one inch apart. Specific gravity, 7.6742.

Strength in lbs. per square inch.	Point of fracture.	REMARKS.
44818	No. 27$\frac{3}{10}$	Put into tin from 22 to 25½. After a strain of 273 lbs. the packing gave way. The temperature of the tin at this time being 550°. After this the bar was broken up at 71°. Broke near the wedges—had not been in tin.
48255	" 25½	Had barely touched the tin.
48592	" 16¾	
48418	" 23⅓	Shorter piece now in from 16¾ to 25½.
49799	" 19¼	
49811	" 22½	
48763	" 1¾	Longer piece now under trial from 1 to 16¾.
50209	" 13½	
49953	" 10⅓	
51129	" 8⅞	
51351	" 6⅓	
51931	" 3½	
		The mean area of the 12 sections of fracture was .000167 square inch *greater* than that of the 28 measured sections.

TABLE LXX.

Experiments on bar No. 224 A. Manufactured by Messrs. Yeatman & Woods of Nashville, Tennessee. Drawn under the ham-

Marks.	Breadth.	Thickness.	Area before trial.	No. of the experiment.	DATE.	Area of the sections of fracture.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight X leverage.	Friction.	Effective strain.
1	.753	.233	.175449		1833.						
2	.754	.233	.175682	1	May 23.	.176202	82	311	9330	466	8864
3	.755	.233	.175915								
4	.753	.233	.175449								
5	.754	.234	.176436	2	"	.175536	82	327	9810	490	9320
6	.754	.232	.174928								
7	.753	.233	.175449								
8	.753	.234	.176202	3	"	.175799	82	327	9810	490	9320
9	.753	.233	.175449								
10	.752	.234	.175968								
11	.753	.234	.176202	4	"	.174928	82	327	9810	490	9320
12	.748	.233	.174284								
13	.753	.232	.174696								
14	.754	.230	.173420	5	"	.174703	82	322	9660	483	9177
15	.754	.232	.174928								
16	.753	.233	.175449								
17	.753	.232	.174696	6	"	.175245	578	364	10920	546	10374
18	.755	.233	.175915								
19	.753	.233	.175449								
20	.752	.233	.175216	7	May 25.	.175216	76	379	11370	568	10802
21	.754	.234	.176436								
22	.754	.235	.177190								
23	.753	.234	.176202	8	"	.176907	76	386	11580	579	11001
24	.753	.234	.176202								
25	.755	.235	.177425								
26	.752	.233	.175216	9	"	.176202	76	400	12000	600	11400
27	.755	.231	.174405								
Mean of 27			.175422	10	"	.175565	76	386	11580	579	11001
Maximum			.177425								
Minimum			.173420	11	"	.175188	76	394	11820	591	11229
Mean of the 2			.175422		Mean of 11	.175772					
Diff. of the 2			.004005								

TABLE LXX.

mer, subsequently reduced by filing, and gauged at every inch. Specific gravity 7.8319.

Strength in pounds per square inch.	Point of fracture.	REMARKS.
50306	No. 8	
53095	" $1\frac{5}{8}$	
53020	" $3\frac{1}{4}$	
53279	" 6	
52511	" $11\frac{3}{4}$	
59197	" $19\frac{7}{8}$	Broke in tin.—Part included in the machine from $17\frac{1}{2}$ to 22.
61649	" 26	
62185	" $21\frac{5}{8}$	
64699	" 24	
62660	" $18\frac{3}{4}$	
64668	" $15\frac{1}{2}$	The mean area of the 11 sections of fracture is .000350 square inch *greater* than that of the 27 measured sections.

TABLE LXXI.

Experiments on bar No. 224 B. Manufactured by Messrs. Yeatman & Woods, at Nashville, Tennessee. Drawn with the hammer,

Marks.	Breadth.	Thickness.	Area before trial.	No. of the experiment.	DATE.	Area of the section at the point of fracture.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Breadth after fracture.
0	.765	.236	.180540		1833.								
1	.759	.237	.179883	1	June 27.	.178947	574°	322	9660	483	9177	51283	
2	.759	.236	.179124										
3	.759	.241	.182919	2	"	.179693	564	329	9870	493	9377	52183	
4	.758	.236	.178888										
5	.758	.237	.179646	3	"	.179646	578	350	10500	525	9975	55526	
6	.758	.237	.179646										
7	.760	.236	.179360	4	"	.179646	578	356	10680	534	10146	56478	
8	.760	.236	.179360										
9	.758	.236	.178888	5	"	.179431	520	368	11040	552	10488	58451	
10	.758	.237	.179646										
11	.758	.236	.178888	6	"	.179646	100	390	11700	585	11115	61872	
12	.758	.237	.179646				app.						
13	.758	.237	.179646	7	"	.180376	100	390	11700	585	11115	61621	
14	.758	.237	.179646				app.						
15	.759	.237	.179883	8	"	.179267	75	398	11940	597	11343	63275	
16	.759	.236	.179124										
17	.754	.237	.178698	9	"	.179503	75	405	12150	607	11543	64305	
18	.758	.236	.178888										
19	.756	.236	.178416										
20	.758	.237	.179646	10	"	.179457	75	390	11700	585	11115	61937	
21	.753	.237	.178461										
22	.755	.238	.179690										
23	.757	.238	.180166				1100						
24	.758	.237	.179646	11	June 29.	.179492	to	168	5040	252	4788	26675	.500
25	.758	.236	.178888				1200						
26	.759	.236	.179124										
Mean of 27			.179494										
				12	"	.179314	75	355	10650	532	10118	56425	
Maximum=			.182919										
Minimum=			.178888	13	"	.179053	75	348	10440	522	9918	55391	
Mean of the 2			.180903	14	"	.179457	75	359	10770	538	10232	57016	
Diff. of the 2			.004031										
					Mn. of 14=	.179494							

TABLE LXXI.

reduced by filing to a nearly uniform size, and gauged at every inch. Specific gravity 7.8046.

Thickness after frac.	Area after fracture.	Area *after*, in parts of that *before* fracture.	Point of fracture.	REMARKS.
			No. 25¼	Part in tin from 4 to 8.
			" 15¼	Do.
			" 13¾	Do.
			" 12	Do.
			" 6¾	Broke in tin.—Temperature had been at 590°.
			" 5¾	
			" 0¼	
			" 4½	
			" 1½	
			" 9¾	This is a different piece from the preceding—part on the opposite side of the hot fracture.
.130	.065000	.362	" 19⅞	Put on 336 lbs. which it bore without signs of yielding—took off one half the weight and then applied a lamp directly below the bar to raise the temperature until it should give way, which it did at a red heat, barely visible in daylight.
			" 15¾	Broke at a part most remote from the portion just heated.
			" 20½	
			" 24¼	The mean area of the 14 sections of fracture is *identical* with that of the 27 measured sections.

TABLE LXXII.

Experiments on bar No. 224 C. Manufactured by Messrs. Yeatman & Woods, at Nashville, Tennessee. Drawn under the hammer,

Marks.	Breadth.	Thickness.	Area of section at the points measured.	Number of the experiment.	DATE.	Area of the section at the point of fracture.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
0	.760	.238	.180880	1	1833. June 29.	.183828	580°	311	9330	466
1	.757	.242	.183194							
2	.756	.241	.182196							
3	.756	.239	.180684	2	"	.182400	590	311	9330	466
4	.756	.241	.182196							
5	.757	.242	.183194							
6	.757	.241	.182437	3	"	.184265	562	378	11340	567
7	.757	.242	.183194							
8	.757	.242	.183194							
9	.760	.241	.183160	4	"	.183171	80	401	12030	601
10	.759	.242	.183678							
11	.761	.243	.184923							
12	.759	.243	.184437	5	"	.182945	80	401	12030	601
13	.760	.242	.183920							
14	.760	.239	.181640							
15	.760	.241	.183160	6	July 6,	.183748	80	351	10530	526
16	.761	.242	.184162							
17	.761	.242	.184162							
18	.761	.243	.184923	7	"	.183160	80	369	11070	553
19	.760	.241	.183160							
20	.760	.241	.183160							
21	.760	.240	.182400	8	"	.182626	77	231	6930	346
22	.761	.241	.183401							
23	.759	.242	.183678							
24	.761	.241	.183401	9	"	.183470	77	249	7470	373
25	.760	.240	.182400							
26	.763	.241	.183883	10	"	.183141	77	253	7590	379
Mean of 27			.183141	11	"	.182650	77	256	7680	384
Maximum			.184923	12	"	.182445	77	237	7110	355
Minimum			.180684							
				13	"	.182529	77	249	7470	373
Mean of these 2			.182803							
Diff. of the 2			.004341	14	"	.181169	77	255	7650	382
					Mean of 14	.183110				

TABLE LXXII.

reduced by filing to a nearly uniform size, and gauged at every inch. Specific gravity, 7.7781.

Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
8864	48219	No. 15⅔	Part in tin from 3 to 6½.
8864	48596	" 14½	
10773	58465	" 12⅓	Being less than 6 inches from the tin, the place of this fracture was probably heated to 150 or 200° at the time. Calculating for this weight (378 lbs.) on the smallest section now in the tin, it gives 59623 lbs. per square inch.
11429	62395	" 8⅔	
11429	62472	" 4¾	After this fracture the section was found to be in breadth, .572; thickness, .159; area .090948; showing the present area to be less than half the original section, for .090948×2=.181896.
10004	54226	" 18⅔	The piece now under trial had been previously tried with only 311 lbs. in the scale, having been broken off at the first experiment.
10517	57420	" 20	The same piece as in the preceding trial.
6584	36052	" 5¾	Short piece.—*Had been in tin.*—Area at the time of this trial .150664. Calculating on this area, we obtain a strength of 43700 lbs. per square inch. This and the following experiments were on annealed sections.
7097	38682	" 23¾	Had not been in tin.
7211	39374	" 25½	Do.
7296	39945	" 21¼	Do.
6755	37025	" 4¼	Had been in tin.
7097	38887	" 1⅔	
7268	40118	" 0⅛	The mean area of the 14 sections of fracture is .000031 square inch *less* than that of the 27 measured sections.

TABLE LXXIII.

Experiments on bar No. 224 D. Manufactured by Messrs. Yeatman & Woods, at Nashville, Tennessee. Drawn by the hammer, }

Marks.	Breadth.	Thickness.	Area of section before trial.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temp. Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Breadth after fracture.
0	.768	.237	.182016										
1	.755	.237	.178935		1833.		o						
2	.756	.239	.180684	1	July 13,	.184558	570	314	9420	471	8949	48489	.518
3	.757	.239	.180923										
4	.759	.241	.182919										
5	.760	.243	.184680										
6	.760	.240	.182400	2	"	.186010	550	314	9420	471	8949	48110	
7	.760	.242	.183920										
8	.759	.242	.183678	3	"	.183920	560	322	9660	483	9177	49891	
9	.758	.242	.183436										
10	.758	.242	.183436	4	"	.184110	540	340	10200	510	9690	52631	
11	.758	.242	.183436										
12	.760	.242	.183920										
13	.760	.243	.184680										
14	.760	.242	.183920	5	"	.178935	440	372	11160	558	10602	59262	
15	.760	.242	.183920										
16	.760	.245	.186200										
17	.760	.245	.186200	6	"	.183436	80	375	11250	562	10688	58265	
18	.760	.244	.185440	7	"	.183678	80	375	11250	562	10688	58189	
19	.760	.244	.185440										
20	.760	.243	.184680	8	"	.183540	80	378	11340	567	10773	58696	
21	.759	.243	.184437										
22	.759	.240	.182160										
23	.759	.241	.182919	9	"	.182970	80	378	11340	567	10773	58878	
24	.759	.241	.182919										
25	.760	.241	.183160										
26	.763	.239	.182357										
				10	July 18,	.180863	76	221	6630	331	6299	34827	
Mean of 27=			.183439										
				11	"	.180475	76	234	7020	351	6669	36952	.456
Maximum=			.186200	12	"	.182892	76	234	7020	351	6669	36464	
Minimum=			.178935	13	"	.182350	76	236	7080	354	6726	36885	
				14	"	.182919	76	236	7080	354	6726	36770	
Mn. of the 2			.182567										
Diff. of the 2			.00725		Mn. of 14 =	.182912							

TABLE LXXIII.

reduced by filing to a nearly uniform size, marked and gauged at every inch. *Specific gravity* 7.8046.

Thickness after frac.	Area after fracture.	Area after, in parts of that before, fracture.	Point of fracture.	REMARKS.
.150	.077700	.421	No $20\frac{1}{2}$	Part in tin from $1\frac{1}{2}$ to $5\frac{1}{2}$. Before the fracture the part from No. 7 to 20 was found to be 15 3-10 inches long, and had consequently stretched 2 3-10 inches or a little more than 1-6 of its original length.
			" $17\frac{1}{4}$	Broke at the remotest part from the tin which is still in the same place as above.
			" 14	
			" $12\frac{1}{4}$	Fracture very near the wedges. This experiment would by calculating on the smallest section in tin give a strength of 54058 lbs. per square inch.
			" 1	Reduced in area at No 1. But not actually broken. It had borne 360 lbs. while at a temperature of 570°. The smallest section in tin, which is the smallest in the bar, is the one on which the calculation is made in the table.
			" $9\frac{1}{2}$	Broke soon after applying the weight.
			" 8	Yielded very gradually.
			" $6\frac{3}{4}$	
			" $5\frac{3}{4}$	The part remaining after this experiment from 0 to No. 5 had become 5.93 in. in length. Extension $=\frac{1}{5.376}$ of the original length.
			" $2\frac{3}{4}$	From this experiment to the end of the series, the trials were on annealed sections.
.130	.059280	.328	" $0\frac{1}{2}$	
			" $25\frac{1}{3}$	
			" $22\frac{1}{4}$	
			" $23\frac{1}{2}$	
				The mean area of the 14 sections of fracture is .000527 square inch *less* than that of the 27 measured sections.

TABLE LXXIV.

Experiments on bar No. 224 E. Manufactured by Messrs. Yeatman & Woods, at Nashville, Tennessee. Drawn by the hammer,

Marks.	Breadth.	Thickness.	Area before trial.	No. of the experim'nt.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
0	.753	.243	.182979		1833.					
1	.753	.239	.179967	1	July 11,	.178224	566°	305	9150	457
2	.753	.238	.179214							
3	.752	.238	.178976	2	"	.178105	570	319	9570	478
4	.752	.237	.178224							
5	.752	.238	.178976	3	"	.178976	554	329	9870	493
6	.750	.237	.177750							
7	.753	.237	.178461	4	"	.177562	573	334	10020	501
8	.753	.236	.177708							
9	.749	.237	.177513	5	"	.178976	560	351	10530	526
10	.752	.237	.178224							
11	.752	.237	.178224	6	"	.178047	560	351	10530	526
12	.753	.237	.178461							
13	.752	.237	.178224	7	"	.178698	560	367	11010	550
14	.754	.236	.177944							
15	.754	.237	.178698	8	"	.179468	82	322	9660	483
16	.754	.237	.178698							
17	.754	.237	.178698	9	July 12,	.178976	82	375	11250	562
18	.754	.237	.178698							
19	.750	.236	.177000	10	"	.180480	82	385	11550	577
20	.751	.236	.177236							
21	.752	.240	.180480	11	"	.177059	82	394	11820	591
22	.752	.240	.180480							
23	.752	.240	.180480	12	"	.180480	82	394	11820	591
24	.751	.240	.180240							
25	.752	.238	.178976	13	"	.173342	82	383	11490	574
26	.752	.238	.178976							
				14	"	.178342	82	383	11490	574
		Mean of 27	.178870							
				15	"	.178321	82	397	11910	595
		Maximum	.182979							
		Minimum	.177000		Mean of 15=	.178337				
		Mn. of these 2	.179989							
		Diff. of the 2	.005979							

TABLE LXXIV.

reduced by filing to a nearly uniform size, marked and gauged at every inch from 0 *to* 26, *inclusive. Specific gravity*, 7.8046.

Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
8693	48776	No. 4	Part in tin from 16 to 20. This was therefore a cold fracture.
9092	51048	" 6½	Cold fracture.
9377	52392	" 26½	Cold fracture.
9519	53576	" 8¾	Warm at the section of fracture. On the opposite part of the bar to the preceding.
10004	55896	" 25¾	Broke near the wedges.
10004	56287	" 9¾	Broke near the wedges, on the side of tin bath opposite to that of the preceding fracture.
10460	58534	" 18	Broke in tin.
9177	51134	" 1⅔	This piece had been broken off in the first experiment on the bar.
10688	59662	" 25	
10973	60799	" 22½	
11229	63419	" 19¼	
11229	62273	" 21¼	
10916	61208	" 11½	Different piece from the preceding.
10916	61208	" 12½	
11315	63453	" 14½	
			The mean area of the 15 sections of fracture is .000533 *less* than that of the 27 measured sections.

TABLE LXXV.

Experiments on bar No. 231, Russian iron. Obtained from Messrs. Jackson & Riddle, iron merchants of Philadelphia. Reduced by ham-

Marks.	Breadth.	Thickness.	Area before trial.	No. of the exp't.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.
1	.800	.239	.191200									
2	.800	.238	.190400									
3	.800	.238	.190400									
4	.799	.244	.194956		1834.							
5	.799	.242	.193358	1	Aug. 9,	.193437	72.°	465	13950	697	13253	68513
9	.798	.240	.191520									
7	.800	.237	.189600	2	"	.191600	72.5	518	15540	777	14763	77051
8	.800	.241	.192800									
9	.797	.240	.191280	3	"	.192800	72.5	518	15540	777	14763	76571
10	.800	.235	.188000									
11	.800	.238	.190400	4	"	.193891	72.5	540	16200	810	15390	79374
12	.800	.239	.191200									
13	.800	.240	.192000	5	"	.198800	73.	525	15750	787	14963	78835
14	.798	.237	.189126									
15	.798	.236	.188328	6	"	.189837	574.	514	15420	771	14649	77166
16	.800	.236	.188800									
17	.800	.237	.189600	7	"	.189126	75.	588	17640	882	16758	88607
18	.800	.237	.189600									
19	.801	.237	.189837	8	"	.188328	75.	609	18270	913	17357	92163
20	.801	.237	.189837									
21	.800	.239	.191200	9	"	.189629	75.	643	19290	964	18326	96641
22	.798	.237	.189126									
Mean of 22			.190980		Mean of 9	.191938						
Maximum			.194956									
Minimum			.188000									
Mn. of the 2			.191478									
Diff. of the 2			.006956									

TABLE LXXV.

mering and filing in the usual way. Specific gravity, 7.8014.

Specific gravity of the parts in the vicinity of the section of fracture.	Point fractured.	REMARKS.
		The first permanent elongation perceived, was taken under a weight of 308 lbs.
7.7945	No. $3\frac{2}{3}$	This fracture developed a seam or flaw in the direction of the *length.*
7.7985	" $12\frac{1}{2}$	Fracture smooth and fine, but not entirely uniform.
7.8231	" 8	Took off 14 lbs. of the weight used in last experiment, and restored them gradually.
7.8702	" $4\frac{2}{3}$	Broke in the gripe of the wedges.
7.7586	" $10\frac{3}{4}$	
7.8307	" $19\frac{1}{3}$	
7.8211	" 14	This fracture presented a steely or crystalline appearance.
7.7650	" 15	Do. (in part.)
7.7831	" $18\frac{1}{8}$	Do.
End piece. 7.7696		
Mn 7.8014		The mean area of the 9 sections of fracture was *greater* than that of the 22 measured sections, by .000958 square inch, which is one half of one per cent. of their mean magnitude.

TABLE LXXVI.

Experiments on bar No. 232, Swedish iron. Obtained from Messrs. Jackson & Riddle,—taken at random from a large number—slit with the chisel lengthwise, and then reduced by hammering and filing to a

Marks.	Breadth.	Thickness.	Area before trial.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight.	Breaking wht. X leverage.	Friction.	Effective strain.
1	.801	.234	.187934								
2	.801	.234	.187934		1834.						
3	.801	.233	.186633	1	Septem.	.187872	72	376	11280	564	10716
4	.800	.233	.186400								
5	.800	.234	.187200								
6	.800	.234	.187200	2	"	.187798	72	393	11790	589	11201
7	.800	.232	.185600								
8	.800	.232	.185600								
9	.800	.233	.186400	3	"	.186809	947	313	9390	469	8921
10	.800	.234	.187200								
11	.800	.233	.186400								
12	.800	.233	.186400	4	"	.185262	56	457	13710	685	13025
13	.800	.232	.185600								
14	.802	.232	.186064	5	"	.186599	56	464	13920	696	13224
15	.802	.233	.186866								
16	.802	.231	.185262	6	"	.186400	56	464	13920	696	13224
17	.802	.231	.185262								
18	.802	.232	.186064	7	"	.187200	56	461	13830	691	13139
19	.808	.233	.188264								
20	.807	.233	.188031	8	"	.186400	56	468	14040	702	13338
21	.801	.233	.186633								
22	.803	.233	.187099	9	"	.187434	55	474	14220	711	13509
23	.803	.233	.187099								
24	.803	.233	.187099	10	"	.186600	55	479	14370	718	13652
25	.806	.233	.187798								
26	.807	.235	.189645	11	"	.188089	55	406	12180	609	11571
27	.807	.233	.188031								
28	.803	.234	.187872	12	"	.187565	55	434	13020	651	12469
29	.802	.234	.187668								
30	.803	.234	.187872	13	"	.187099	55	462	13860	693	13167
31	.805	.232	.186760								
					Mn. of 13 =	.187009					
Mean of 31			.186935								
Maximum			.188264								
Minimum			.185600								
Mn. of the 2			.186932								
Diff. of the 2			.002664								

TABLE LXXVI.

suitable size for the experiments. Specific gravities of the different sections as in the last column, mean of 6 *trials*, 7.4587.

Strength in lbs. per square inch.	Point of fracture.	REMARKS.
57039	No. 28	First perceptible elongation taken with 196 lbs. in the scale. Specific gravity of the end part, 7.6106.
59644	" 25	With 380 lbs., 24 inches in length had become 25 *nearly*.
52401	" 18⅓	Used the pyrometer with a new screw and revolving weight. Each degree weighs 4–7 of a grain of steam. Specific gravity 7.5118.
70030	" 16	
70868	" 14⅔	Specific gravity 7.4414.
70965	" 11	
70186	" 5½	
71555	" 9	
72073	" 1⅔	
73161	" 4¼	Specific gravity 7.5052.
61518	" 19¾	Specific gravity 7.367.
66478	" 20⅓	Specific gravity 7.3133.
70376	" 22⅔	The mean area of the 13 sections of fracture is .000074 square inch *greater* than that of the 31 sections measured before trial.

TABLE LXXVII.

Experiments on bar No. 233. Swedish iron. Reduced to uniform size as in the preceding table. Specific gravity, by a mean of 7 trials on

No. of the mark.	Breadth.	Thickness.	Area of sections measured before trial.	No. of the experim't.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Weight in the scale.	Weight × leverage.	Friction.
1	.802	.226	.181252		1836.					
2	.800	.227	.181600	1	April 16,	.181178	65°	371	11130	556
3	.800	.226	.180800							
4	.806	.226	.181478							
5	.803	.225	.180675	2	"	.179424	65	363	10890	544
6	.804	.227	.182508							
7	.803	.227	.182481							
8	.802	.227	.182054	3	"	.181252	65°+	336	10080	504
9	.802	.227	.182054							
10	.802	.227	.182054							
11	.801	.226	.181026	4	"	.181653	50	403	12090	604
12	.802	.224	.179648							
13	.802	.226	.181252							
14	.801	.225	.180225	5	"	.180348	50	403	12090	604
15	.801	.225	.180225							
16	.801	.225	.180225		1837.					
17	.801	.225	.180225	6	Jan. 5,	.180225	53°	378	11340	567
18	.801	.225	.180225							
19	.801	.225	.180225							
20	.802	.225	.180450	7	"	.180225	40	426	12780	639
21	.802	.225	.180450							
22	.802	.224	.179648							
23	.802	.226	.181252	8	"	.180450	40	413	12390	619
24	.802	.227	.182054							
25	.802	.226	.181252							
26	.801	.227	.181827	9	"	.180225	40	420	12600	630
27	.798	.226	.180348							
28	.799	.227	.182373							
29	.800	.226	.180800	10	"	.181252	40	408	12240	612
30	.801	.224	.179424							
31	.800	.226	.180800							
				11	"	.181026	40	399	11970	598
		Mean of 31	.181187							
		Maximum	.182508	12	"	.182394	40	408	12240	612
		Minimum	.179424							
		Mean of the 2	.180966	13	"	.182054	40	413	12390	619
		Diff. of the 2	.003084							
					Mean of 13	.180900				

TABLE LXXVII.

different parts of the bar, 7.4983.

Effective strain.	Strength in lbs. per square inch.	Point of fracture.	REMARKS.
10574	58362	No. $4\frac{3}{8}$	Short piece only embraced between the heads of the machine.
10346	57662	" 30	Shorter portion than before.
9576	52838	" 23	In hot metal above 650°.
11486	63230	" $24\frac{1}{2}$	
11486	63688	" 27	
10773	59775	Not bro.	Tried in tin from 16 to 19. Not broken. Elongation on the part in tin, after trial, .25 inch.
12141	67365	" $17\frac{1}{4}$	
11771	65231	" $20\frac{1}{4}$	
11970	66417	" 15	
11628	64153	" $0\frac{1}{2}$	
11372	62819	" 11	
11628	63203	" $6\frac{1}{2}$	
11771	64656	" $8\frac{1}{4}$	The mean area of the 13 sections of fracture is .00287 *less* than that of the 31 sections measured before trial.

TABLE LXXVIII.

Experiments on bar No. 237, a specimen of bar iron manufactured by H. A. Grubb and heirs, Lancaster County, Pennsylvania. Ore taken }

Marks.	Breadth.	Thickness.	Area of the sections measured before trial.	No. of the experiment.	DATE.	Area at the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Breadth of section after fracture.
1	.795	.250	.198750										
2	.793	.250	.198250										
3	.796	.250	.199000		1835.								
4	.797	.250	.199250	1	July 18,	.195624	56°4	392	11760	588	11172	57109	.628
5	.796	.250	.198500										
6	.796	.252	.200592										
7	.796	.252	.200592										
8	.794	.252	.200088	2	July 24,	.198792	83	420	12600	630	11970	60213	.621
9	.791	.250	.197750										
10	.790	.251	.198290										
11	.794	.251	.199294	3	"	.198334	83	431	12930	646	12284	61935	.648
12	.794	.251	.199294										
13	.792	.247	.195624										
14	.795	.251	.199545	4	"	.199125	83	436	13080	654	12426	62403	.640
15	.795	.250	.198750										
16	.791	.246	.194586										
17	.796	.246	.195886	5	"	.200592	83	448	13440	672	12768	63651	.640
18	.792	.252	.199484										
19	.792	.252	.199484										
20	.794	.250	.198500	6	"	.198750	575	408	12240	612	11628	58508	.668
21	.795	.251	.199545										
22	.795	.249	.197955										
23	.796	.247	.196614	7	"	.199015	110	424	12720	636	12084	60719	.663
Mean of 23 =			.198502										
				8	"	.195016	100	434	13020	651	12369	63396	.619
Maximum			.200592										
Minimum			.194586										
				9	"	.198110	100	452	13560	678	12882	65024	.632
Mean of the 2			.197589										
Diff. of the 2			.006006		Mn. of 9 =	.198151							

TABLE LXXVIII.

from the Cornwall ore-bank. Drawn under the hammer, reduced by filing and gauged at every inch. Specific gravity, 7.740.

Thickness after fracture.	Area of section after fracture.	Area *after* comp. with that *before* trial taken as unity.	Point of fracture.	REMARKS.
.178	.111784	.571	No. 13	The load first tried in making this experiment was 363 lbs., which the bar bore for some time, but on changing it for 392 it gave way very soon—result supposed to be a little too high—part in tin from 4 to 7 inclusive.
.181	.112401	.565	" $10\frac{1}{2}$	
.192	.124416	.627	" $8\frac{3}{4}$	
.195	.124800	.626	" $3\frac{1}{2}$	
.199	.129360	.644	" 7	
.200	.123600	.621	" $21\frac{1}{2}$	Part in tin from $16\frac{1}{2}$ to 21. The temperature of the section of fracture at the moment of breaking was judged to be not less than 400°.
.186	.123318	.619	" $14\frac{2}{3}$	
.178	.110182	.565	" $15\frac{7}{8}$	
.199	.125768	.634	" $17\frac{5}{8}$	
		.608		The mean area of the 9 sections of fracture is .000350 square inch *less* than that of the 23 measured sections.

Results of experiments on wrought iron not rolled into plate.

Among the facts disclosed in this range of results, those respecting English cable-bolt iron, are given in tables LXI., LXII. and LXIII. But much of the matter in the first two of these tables, refers to the influence of high temperatures. They, however, furnish a mean result, on bar 214, for the strength in the cold state, of 57987 pounds to the square inch. On bar 212, an experiment, on a deeply filed section, gave 59975, while two trials on 213 give a mean of 59351 pounds. Hence the mean of these three results, viz: 59105 pounds, represents the strength of the best English cable-bolt iron under ordinary circumstances. Table LXIII. presents the results on two portions of the above iron, one cut from bar 213, the other from 214, and on these portions, the effect of *hammer-hardening* was tried. The bars when drawn out under the hammer, previous to being filed down, were hammered until nearly, or quite, cold. It will be seen that the lowest result on these two specimens was 65718, the highest 75045, and the mean of 8 trials, 71000 pounds. From this statement, it is apparent that the process applied augments, very sensibly, the tenacity of the material; for the lowest result in this table, is 5743 pounds, or 9.5 per cent., above the highest of the three just detailed, as given by the metal in its ordinary state; while the mean of the hammer-hardened specimens, is 11282 pounds or 19.2 per cent. above the mean strength of those which had been only hammered out in the ordinary way, and left to cool off from a red heat without the simultaneons application of any mechanical action.

Table LXIV. contains the experiments on a specimen of wire, about one-third of an inch in diameter. The maximum strength at 50°, is 88354 pounds per square inch, the minimum 72325, (the latter being on a part annealed before trial,) and the mean of all the trials 81387.

Experiments 3, 4, 5, and 6, on this wire, gave results so nearly identical, that we may perhaps more properly assume their mean as its true average strength, equal to 84186 pounds per square inch, at from 60 to 66 degrees Fahrenheit. From *this* mean the diminution by annealing, is 14 per cent.

By the first 5 experiments, in table LXXV., it appears that the strength of Russian bar iron, at ordinary temperatures, is 76069 pounds per square inch. It will be perceived that the specific gravity of this specimen is considerably higher than that of most other samples of metal, which we have examined. Its superiority in point of tenacity is, probably, attributable, in a great degree, to the refining process to which it had been subjected. The fracture was of a peculiarly fine, fibrous appearance, and had generally a tolerably regular bevel or *chisel* edge, across the *thickness* of the bar.

In the tables numbered from LXV. to LXIX., will be found an account of experiments on 5 bars of iron, manufactured in Missouri; and in those numbered from LXX. to LXXIV., are recorded the operations on the same number of bars made near Nashville in Tennessee. In the case of these, as well as other bars on which some of the trials were marked as at elevated temperatures, the fractures often took place at points so remote from the source of heat, that the results really belong to "ordinary temperatures." Including fractures made under the circumstances just alluded to, the number of results obtained at those temperatures, on the Missouri iron, is 22, and the mean strength 47909 pounds per square inch. On the Tennessee iron, were made, under similar circumstances, 21 experiments, giving a mean strength of 52099 pounds. The Missouri bars appeared to possess a coarse fibrous structure, and were judged to have undergone but little refining in bringing the metal to a malleable state.

Table LXXVIII. exhibits the tenacity of iron manufactured by Messrs. Grubb, of Lancaster county, Pennsylvania, as 58661 pounds per square inch.

While on this subject, we may refer to some following tables of experiments on iron from Salisbury, Connecticut, manufactured from different sorts of pig-metal, reserving, however, the particular discussion of those tables to a subsequent section of this report. It will be found on inspecting table LXXIX. that forty experiments, at comparable temperatures, were made on the materials from that quarter, the mean result of which is a strength of 58009 pounds per square inch.

In connexion with the present topic, may also be mentioned the result of experiments on specimens of iron manufactured in Centre County, Pennsylvania, an account of which will be found in table XCVII. The mean strength of three bars, as given by 15 experiments, is 58400 pounds. Table CII. includes, among others, 10 experiments, at ordinary temperatures, on Phillipsburg wire of smaller sizes than that already mentioned. Of these, the larger—.19 inch in diameter—will be found to have exhibited, at 5 trials, a mean strength of 73880 pounds; and that which had a diameter of .156 inch, a strength of 89162 pounds per square inch.

Collecting together the foregoing details, we have foı the strength

Of Missouri bar iron, at ordinary temperatures, by		22 exp.	47909 pounds.
Slit rods, (Nos. 180 and 182.)		2	50000
Tennessee bar,		21	52099
Salisbury, Conn.,		40	58009
Swedish bar,		4	58184
Centre Co., Pa.,		15	58400
Lancaster Co., Pa.,		2	58661
English Cable iron,		5	59105
Do. hammer hardened		8	71000
Russian bar,		5	76069
Phillipsburg wire, diam.	.333	13	84186
	.190	5	73888
	.156	5	89162
Cast steel, (Tab. LIX.)		1	130681

Strength of iron made from different sorts of Pig-metal.

The experiments to determine the effect of different kinds of pig-metal, either separate or in mixture, when converted into wrought iron, by the same refining process, were performed on bars furnished by the Salisbury Iron Company, of Salisbury, Connecticut, of which one specimen, from which were formed the two bars 218 A., 218 B., was produced from *dead gray pig;* 219 A., and 219 B., were from a specimen formed from *lively gray pig;* 220 A. and 220 B., from *mottled pig;* 221 A. and 221 B. from *white pig;* and 222 A. and 222 B., from a mixture of all these kinds together. By a reference to the tables (from LXXX. to LXXXVIII. inclusive) containing details of the trials upon these bars, it will be seen that on all of them, some experiments were made at high temperatures, and of course that the purpose of the present comparison can be properly accomplished, only by referring to those, which were made at, or near the same temperature. The experiments at ordinary temperatures embracing the mean strength, as well as the irregularities of structure, are preferred as most satisfactory in referrence to this point. In presenting these results, care has

been taken to exclude all those trials in which the effect of heat would be appreciable, either during or subsequent to the time of trial.

It will be seen that if we take into view all the bars of this iron, on which experiments were made after they were reduced to a uniform size, and exclude only 219 B., on which the sections were all deeply filed, the advantage will appear to be in favour of the metal manufactured from *white* pig ; next to which, is that produced from *lively gray*, giving 98½ per cent. of the strength of the first. Next, in the order of strength, will be found the iron from *dead gray pig*, inferior to the first by 1 2-3 per cent.; next, that from the mixture of the four kinds of pig which appears to have been weaker than the same by 4 4-10 per cent.; and, finally that from mottled pig in which the inferiority extended to 5 per cent. The following table (LXXIX.) exhibits, at a view, the comparative strength, and the respective degrees of uniformity of the several bars, with the strength of some of them at high temperatures.

At elevated temperatures, the results, except that on No. 219 B, are much nearer to each other, than those at the points selected for our general comparison. On that bar, the trials were upon filed sections. The experiment at 573°, giving a strength of 66620, exceeded those at corresponding temperatures on the other bars, by an average of about 6222 lbs., or 10⅓ per cent.; while the two experiments which were made upon it at low temperatures, as will be seen by table LXXXII., gave results, the mean of which being 66724 lbs., surpasses that of the other nine bars by 9275 lbs., or by 16 1-10 per cent. Hence we are compelled to believe that this specimen, as it came to hand, had undergone the process of hammer-hardening,—a process which the direct experiments of the committee have proved to be capable of essentially modifying the tenacity of the metal.

From the above, it appears, that the greatest difference of strength which under ordinary circumstances, can be attributed to differences in the pig-metal* from which wrought iron is produced, is about 5 per cent., and that under every mode of trial, the article formed from a mixture of different kinds of pig, is inferior in tenacity and uniformity to those derived from either of the ingredients, unless we except that from *mottled gray*. And even this latter will, on a comparison of all the experiments made upon it, under every circumstance, be found superior to the bars from *mixed* castings.

If we take into the amount 219 B., the order of values, beginning with the highest, will be *lively gray*, *white*, *dead gray*, *mixed pigs*, *mottled ;* and if we arrange them in the order of their values, as deduced from a comparison of *all the experiments*, on each kind of iron, with the number of trials made on each, we have :—1. *lively gray* 15 experiments.—2. *white* 27 experiments.—3. *mottled gray* 36 experiments.—4. *dead gray* 21 experiments.—5. *mixed metals* 31 experiments.

So far as these experiments may be considered decisive of the question, they favour the lighter complexion of the cast metal, in preference to the darker and mottled varieties, and they place the mixture of different sorts, among the worst modifications of the materials to be used, where the object is mere tenacity.

* It will be understood that this remark does not apply to pig-iron contaminated with sulphur, phosphorus, copper, or other similar impurities; but only to such as contain different proportions of the *ordinary* ingredients.

TABLE LXXIX.

Comparative table of the effects of using different sorts of pig metal.

No. of the bar.	No. of the expt's. on each bar, made at the comparable temp.	Strength exhibited at each experiment.	Mean Strength of each bar.	Difference of maximum and minimum of each bar.	Amount of irregularity in parts of the mean strength.	Name of the pig, and mean strength of the two bars of each kind.	REMARKS.
218 A.	1 2 10 11	58683 57565 58459 61225	59155	4360	.073	Dead gray pig.	This bar, at 554°, possessed a strength of 60457 lbs. per square inch.
218 B.	1 2 3 4 5	53314 55575 56339 58682 60478	56877	7164	.126	58016	
219 A.	1 2 3 4 8	52257 59418 60204 57854 60645	58075	8388	.144	Lively gray.	This bar at 630° broke with 60010 lbs. per. sq. in.
219 B.	2 3	65640 67808	66724	2168	.032	62399	These two experiments were made on very deeply filed sections. At 573°, this bar gave 66620.
220 A.	1 2 3	52503 52119 53999	52873	1496	.028	Mottled.	At 575° broke with 60988 lbs. per sq. inch.
220 B.	1 2 3 10	58642 58108 58125 62138	59252	4027	.068	56062	
221 A.	1 8 9	53021 62862 63081	59654	10060	.168	White.	At 520° broke under a strain of 60322 lbs. per. sq. inch.
221 B.	1 2 11 12 13	54764 56054 57901 61736 61140	58319	6972	.119	58986	
222 A.	1 2 3 4 5	49597 58924 60651 61915 58895	57996	12318	.212	Mixed pigs.	
222 B.	1 2 3 4	51132 53703 54407 59652	54843	8500	.155	56419	This bar gave as the mean of two experiments at 572° 60215 lbs.

TABLE LXXX.

Experiments on bar 218 A. Manufactured by the Salisbury Iron Company, at Salisbury, in Connecticut, the ore being obtained from "Ore Hill," in that town. The kind of pig used, the "dead gray." Refined after the English method; a loup made and a "gun bar" formed

Marks.	Breadth.	Thickness.	Area at the sections measured before trial.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature Fahrenheit.	Breaking weight in the scale.	Breaking weight X leverage.	Friction.	Effective strain.
0	.771	.231	.178101		1833.						
1	.755	.231	.174405	1	April 20,	.172895	556°	356	10680	534	10146
2	.755	.230	.173650								
3	.755	.229	.172895	2	"	.176253	71	356	10680	534	10146
4	.755	.230	.173650								
5	.755	.230	.173650	3	April 25,	.172666	554	366	10980	549	10431
6	.754	.230	.173420								
7	.756	.230	.173880	4	"	.173420	71	397	11910	595	11315
8	.755	.230	.173650								
9	.753	.230	.173190	5	"	.173420	71	397	11910	595	11315
10	.753	.230	.173190								
11	.754	.229	.172666	6	"	.173765	68	388	11640	582	11058
12	.754	.229	.172666								
13	.754	.229	.172666	7	"	.173470	68	396	11880	594	11286
14	.754	.230	.173420								
15	.754	.230	.173420	8	"	.173190	68	404	12120	606	11514
16	.754	.230	.173420								
17	.754	.230	.173420	9	"	.173497	68	392	11760	588	11172
18	.755	.227	.171385								
					Mn. of 9 =	.173611					
Mean of 19			.173512								
Maximum			.173101								
Minimum			.171385								
Mn. of these 2			.174743								
Diff. of the 2			.001716								
Experiments on the specimen as received, filing successively two different sections											
	Br.	Th.									
	.486	.361		10	April 22,	.153576	50	315	9450	472	8978
	.502	.441		11	"	.221382	68.5	481	14430	721	13709

TABLE LXXX.

expressly for the purpose of affording a specimen for these experiments. The specimen received was drawn out into two bars, A and B, under the hammer, previously to which, however, two sections were filed on the edges and a fracture made at each. Specific gravity 7.7397.

Strength in pounds per square inch.	Point of fracture.	REMARKS.
58683	No. 3	Part in tin from $11\frac{1}{2}$ to $15\frac{1}{2}$. Fracture near the wedges.
57565	" $0\frac{1}{2}$	
60412	" $12\frac{3}{4}$	Broke in tin.
65246	" $14\frac{7}{8}$	Had been in tin at this point.
65246	" $16\frac{3}{4}$	
63638	" $6\frac{3}{4}$	
65079	" $8\frac{1}{2}$	
66482	" $9\frac{3}{4}$	Near the tinned part.
64392	" $5\frac{2}{3}$	Had not been in or near the tin. The mean area of the 9 sections of fracture is .000099 square inch greater than that of the 19 sections measured before trial.
and breaking it at each.		
58459		This section was filed very deep before the bar had been reduced to uniform size.
61925		Filing much less than in the preceding section.

TABLE LXXXI.

Experiments on bar No. 218 B. Manufactured by the Salisbury Iron Company, at Salisbury, in Connecticut. The ore obtained from "ore hill" in that town. The kind of metal used, "dead gray pig." Refined after the English method.

Marks.	Breadth.	Thickness.	Areas before fracture.	No. of the exp't.	DATE.	Area of the section of fracture.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
0	.763	.227	.173206		1833.					
1	.761	.227	.172747	1	April 27,	.174269	580°	326	9780	489
2	.761	.226	.171986							
3	.761	.227	.172747							
4	.761	.227	.172747	2	"	.174879	96	341	10230	511
5	.761	.227	.172747							
6	.761	.229	.174269							
7	.761	.230	.175030	3	"	.175030	90	346	10380	519
8	.761	.230	.175030							
9	.761	.230	.175030							
10	.761	.230	.175030	4	"	.174840	74.5	360	10800	540
11	.761	.230	.175030							
12	.761	.229	.174269							
13	.761	.230	.175030	5	"	.174840	74	371	11130	556
14	.761	.230	.175030							
15	.762	.229	.174498							
16	.762	.230	.175260	6	May 2,	.175030	77	400	12000	600
17	.761	.229	.174269							
18	.761	.229	.174269							
18.3	.762	.230	.175260	7	"	.172747	77	400	12000	600
		Mean of 20	.174173							
				8	"	.172747	77	400	12000	600
		Maximum	.175260							
		Minimum	.171986							
				9	"	.172747	77	398	11940	597
		Mean of the 2	.173623							
		Diff. of the 2	.003274							
				10	"	.175030	77	398	11940	597
					Mean of 10	.174186				

TABLE LXXXI.

A loup made, and a gun bar formed expressly for the purpose of affording a specimen for these experiments. Drawn under the hammer, reduced by filing, and gauged at every inch from 0 *to* 18 3–10 *inclusive. Specific gravity*, 7.7397.

Effective strain.	Strength in lbs. per square inch.	Point of fracture.	REMARKS.
9291	53314	No. 17½	In tin from 3 to 6½.
9719	55575	" 15½	
9861	56339	" 14	
10260	58682	" 12¾	
10574	60478	" 11¼	
11400	65132	" 10	
11400	65992	" 5	Broke without additional weight.
11400	65992	" 3½	Had been in tin.
11343	65662	" 1	
11343	64806	" 8½	Mean area of 10 sections of fracture is *greater* than that of 20 measured sections by .000013.

TABLE LXXXII.

Experiments on bars No. 219 *A and* 219 *B. Manufactured by the Salisbury Iron Company, at Salisbury, in Connecticut, the ore obtained from "Ore Hill," in that town. The kind of pig used,* lively gray. *Refined after the English method. A loup made and a gun*

Marks. *Bar No. 219 A.*	Breadth.	Thickness.	Area of the measured sections before trial.	Marks.	Breadth.	Thickness.	Area after trial.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight X leverage.
0	.754	.200	.150800										
1	.757	.197	.149129										
2	.759	.198	.150282						1833.				
3	.757	.199	.150643					1	Jan. 26,	.145626	63°	267	8010
4	.758	.199	.150842	Meas. after the 9th exper't.									
5	.756	.196	.148176	5	.713	.168	.119784						
6	.754	.196	.147784	6	.713	.187	.133331						
7	.755	.197	.148735	7	.717	.189	.135513	2	"	.147227	50.5	307	9210
8	.755	.197	.148735	8	.722	.190	.137180	3	"	.146286	55.5	309	9270
9	.755	.197	.148735	9	.726	.186	.135036	4	Feb. 2,	.150742	596	306	9180
10	.755	.196	.147980	10	.723	.188	.135924	5	"	.148176	630	312	9360
11	.752	.197	.148144	11	.714	.188	.135232	6	"	.147236	59	324	9720
12	.753	.197	.148341	12	.711	.186	.132246	7	"	.147420	60	341	10230
13	.755	.198	.149490	13	.712	.183	.130296	8	"	.150382	60	320	9600
14	.755	.197	.148735	14	.701	.180	.126180						
15	.756	.196	.148176					9	Feb. 7,	.148176	574	335	10050
16	.756	.195	.147420	16	.670	.175	.117250						
17	.758	.196	.148568	17	.715	.185	.132275	10	"	.149238	54	351	10530
18	.757	.197	.149129	18	.720	.188	.135360						
19	.757	.196	.148372	19	.721	.187	.134827	11	"	.148242	54	355	10650
20	.757	.193	.146101										
21	.756	.192	.145152					12	"	.148735	60	361	10830
22	.756	.195	.147420										
23	.757	.196	.148372					13	"	.148016	65	367	11010
24	.755	.198	.149490										
25	.757	.197	.149129										
26	.754	.194	.146276										
26.4	.753	.196	.147588										
Mean of 28			.148478		Breadth.	Thick.							
Maximum			.150842		.746	.199		1	"	.148454	572	347	10410
Minimum			.145154		.751	.196		2	"	.147196	65.25	339	10170
					.729	.192		3	"	.139968	65	333	9990
Mn. of the 2			.147998										
Diff. of the 2			.005688										

TABLE LXXXII.

bar formed for these experiments. Drawn under the hammer, and bar A. reduced to a uniform size by filing. Bar B. filed deeply at three several points and broken at each filing. Specific gravity 7.8004.

Friction.	Effective strain.	Strength in lbs. per square inch.	Weight producing extension.	Extension measured before the first fracture while the bar was relieved from strain.	Point fractured.	REMARKS.
400	7610	52257	112 203 215 225 235 244 252 260 267	1st percept. .50 in 24 .78 " 1.00 " 1.27 " 1.60 " 1.89 " 2.44 " 2.51 Broke.	No. $20\frac{1}{2}$	Broke at the smallest section in the bar.
460	8750	59418			$25\frac{2}{3}$	
463	8807	60204			$21\frac{1}{2}$	
459	8721	57854			$3\frac{1}{2}$	Part in tin from $13\frac{1}{2}$ to 17.
468	8892	60010			15	Broke in tin at the hottest part.
486	9234	62036			$19\frac{1}{2}$	
511	9719	65903			16	
480	9120	60645			$0\frac{1}{4}$	
502	9548	64437			5	Broke near the wedges, part in tin from $7\frac{1}{2}$ to $10\frac{1}{2}$.
526	10004	67033			$13\frac{1}{3}$	Fracture farthest point from the part heated in the last experiment.
532	10118	68253			$11\frac{1}{2}$	Part last in tin not yet broken.
541	10289	69175			$7\frac{1}{3}$	This part was in the packing at the last experiment in hot metal.
550	10460	70668			$9\frac{\ }{6}$	Had been in tin at 574°. The mean area of the 13 sections of fracture is .000074 square inch *less* than that of the 28 measured sections.
520	9890	66620				Broke in tin.
508	9662	65640				Cold fracture.
499	9491	67808				Do.

TABLE LXXXIII.

Experiments on bar No. 220 A. Manufactured by the Salisbury Iron Company, at Salisbury, in Connecticut. The ore obtained from "Ore Hill," in that town. The kind of pig used, mottled. *Refined after the English method. A loup made, and a gun bar formed*

Marks.	Breadth.	Thickness.	Area before trial.	Marks.	Breadth.	Thickness.	Area after trial.	No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.
0	.762	.215	.163830	Measured after exp't. 9th.					1833.			
1	.762	.215	.163830	10	.702	.194	.136188	1	Feb. 23,	.163400	69.5°	301
2	.762	.216	.164592	11	705	.197	.138885					
3	.763	.215	.164045	12	.710	.198	.140580	2	"	.164045	49.5	300
4	.763	.216	.164808	13	.707	.198	.139986					
5	.763	.215	.164045	14	.705	.196	.138180	3	"	.163615	49.5	310
6	.762	.215	.163830	15	.709	.199	.141091					
7	.762	.215	.163830	16	.711	.199	.141489	4	"	.163400	620.	335
8	.760	.215	.163400	17	.716	.200	.143200					
9	.760	.215	.163400	18	.704	.197	.138688	5	"	.163830	650.	363
10	.760	.216	.164160	19	.720	.200	.144000					
11	.762	.216	.164592	20	.721	.200	.144200	6	Feb. 28,	.163830	60.	384
12	.759	.215	.163185	21	.718	.199	.142882					
13	.758	.216	.163728	22	.713	.198	.141174	7	"	.164426	55.	386
14	.759	.216	.163944	23	.706	.196	.138376					
15	.760	.215	.163400	24	.708	.197	.139476	8	"	.164299	55.	386
16	.763	.215	.164045	25	.703	.195	.137085					
17	.762	.214	.163068									
18	.761	.214	.162854	After experiment 12.				9	"	.164211	55.	391
19	.762	.214	.163068	12	.701	.199	.139499					
20	.762	.215	.163830	13	.700	.198	.138600					
21	.762	.215	.163830	14	.696	.197	.137112	10	"	.164448	580.	344
22	.762	.215	.163830	15	.693	.194	.134442					
23	.761	.215	.163615					11	"	.163507	580.	345
24	.760	.215	.163400									
25	.761	.215	.163615	18	.673	.190	.127870	12	"	.163556	575.	350
26	.760	.215	.163400	19	.708	.200	.141600					
27	.762	.215	.163830	20	.710	.198	.140580	13	"	.163780	56.5	354
28	.763	.215	.164045	21	.710	.197	.139870					
29	.763	.215	.164045	22	.704	.201	.141504	14	"	.164376	57.5	354
29.6	.760	.215	.163400	23	.698	.193	.134714	15	"	.163321	58.5	372
								16	Mar. 2,	.163728	59.5	372
		Mean of 31	.163755					17	"	.163782	59.5	372
								18	"	.163400	60.5	368
		Maximum	.164808					19	"	.163776	60.5	368
		Minimum	.162854					20	"	.163322	61.	381
								21	"	.162907	61.	381
		Mn. of these 2	.163831									
									Mean of 21	.163755		
		Diff. of the 2	.001954									

TABLE LXXXIII.

expressly for these experiments. Drawn under the hammer, reduced by filing, and gauged at every inch from 0 *to* 26.6, *inclusive. Specific gravity*, 7.7855.

Weight X leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	Point of fracture.	REMARKS.
9030	451	8579	52503	No. 9	
9000	450	8550	52119	" 29	A part not included in the first experiment, the bar being too long to be taken all at once into the machine.
9300	465	8835	53999	" 26½	
10050	502	9548	58433	" 8	Part in tin from 3½ to 6. After this experiment, sent the bar forward and took hold again, without changing the tin.
10890	544	10346	63151	" 7	Broke at the coldest part.
11520	576	10944	66801	" 6	
11580	579	11001	66905	" 4½	
11580	579	11001	66958	" 3⅓	
11730	586	11144	67864	" 1½	This section of the bar is now finished. Part from 9 to 26½ was then gauged again. This section had not been in tin.
10320	516	9804	59618	" 10⅔	Broke near the wedges. Part in tin from 15 to 18½.
10350	517	9833	60138	" 24½	Broke near the wedges.
10500	525	9975	60988	" 16½	Broke *in the tin.*
10620	531	10089	61601	" 9½	Within the gripe of the wedges.
10620	531	10089	61378	" 10½	Do. do.
11160	558	10602	64915	" 12¼	
11160	558	10602	64754	" 13	
11160	558	10602	64610	" 13¾	Near the wedges.
11040	552	10488	64186	" 24	Remote from tinned part.
11040	552	10488	64039	" 22¼	
11430	571	10859	66488	" 19⅓	
11430	571	10859	66658	" 18¼	
					The mean area of the 21 sections of fracture is *identical* with that of the 31 measured sections.

TABLE LXXXIV.

Experiments on bar No. 220 B. Manufactured by the Salisbury Iron Company, at Salisbury, Connecticut. The ore obtained from "Ore Hill," in that town. The kind of pig employed, the mottled. *Refined after the English method. A loup made and a gun bar formed*

Marks.	Breadth before trial.	Thickness before trial.	Area before trial.	Marks.	Breadth after trial.	Thickness after trial.	Area after trial.	No. of the exp't.	DATE.	Areas of section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.
0	.752	.220	.165440	Measures taken after the first experiment.									
1	.756	.218	.164808	No.					1833.				
2	.756	.218	.164808	5	.697	.199	.138703	1	Feb. 21,	.163296	63.5°	336	10080
3	.756	.216	.163296	Smallest at beginning.									
4	.756	.217	.164052	8	.719	.208	.148833						
5	.752	.217	.163184	Largest at beginning.									
6	.754	.217	.163618	24¾	.697	.197	.137309						
7	.757	.219	.165783	Smallest section at present.				2	"	.164797	575	336	10080
8	.754	.218	.164372										
9	.756	.218	.164808										
10	.756	.218	.164808					3	"	.164749	62.5	336	10080
11	.753	.218	.164154										
12	.754	.218	.164372					4	"	.164749	576	347	10410
13	.754	.218	.164372										
14	.754	.218	.164372					5	"	.164907	572	361	10830
15	.756	.218	.164808					6	"	.164749	580	371	11130
16	.754	.218	.164372					7	"	.164530	67	389	11670
17	.754	.218	.164372					8	Feb. 23,	.164907	67	394	11820
18	.754	.219	.165126					9	"	.165126	67	397	11910
19	.754	.218	.164372	Measurements taken after the sixth experiment.				10	"	.164797	67	397	11910
20	.754	.219	.165126										
21	.754	.218	.164372	21	.682	.196	.133672	11	"	.165124	71.5	360	10800
22	.754	.219	.165126	22	.697	.200	.139400						
23	.754	.219	.165126	23	.677	.196	.132692	12	"	.163329	550	364	10920
24	.752	.219	.164688	24	.665	.191	.127015						
25	.753	.219	.164907	25	.668	.193	.128924	13	"	.164808	590	364	10920
26	.753	.219	.164907	26	.707	.200	.141400						
27	.753	.218	.164154	27	.717	.206	.147702	14	"	.165077	61	388	11640
28	.753	.219	.164907	28	.713	.203	.144739	15	"	.164481	61	371	11130
29	.753	.219	.164907					16	"	.164590	61.25	385	11550
30	.752	.219	.164688					17	"	.164372	61.25	385	11550
Mean of 27			.164587					18	"	.164372	61.25	393	11790
Maximum			.165783										
Minimum			.173184						Mn. of 18	.164598			
Mn. of the 2			.164483										
Diff. of the 2			.002599										

TABLE LXXXIV.

expressly for these experiments. Drawn under the hammer, reduced by filing to a nearly uniform size and gauged at every inch, from 0 to 30. Specific gravity, 7.7855.

Friction.	Effective strain.	Strength in pounds per square inch.	Weights producing elongation.	Elongation after being relieved from each wht.	Point of fracture.	REMARKS.
504	9576	58642	180 184 284 289 336	1st perman. 1-40 in. in 24 24 bec. 26.5 " 27. Broke.	No. 3	The bar was too long to be all put in. Took the part between 0 and 24 being the most uniform—the first elongation was under 23-48 of the breaking weight.—Very uniformly stretched.
504	9576	58108			$29\frac{1}{2}$	In tin from $23\frac{1}{2}$ to $26\frac{1}{2}$. Broke near the wedges,—this part not strained in the first experiment. Broke very soon under the same weight as before—probably would have broken with a little less.
504	9576	58125			$17\frac{1}{2}$	Weight put on gradually.
520	9890	60030			$19\frac{1}{2}$	From $22\frac{1}{2}$ to $25\frac{1}{2}$ now in tin. Broke near the wedges.
541	10289	62393			$28\frac{1}{2}$	Fracture at the opposite end to the preceding.
556	10574	64182			$20\frac{1}{2}$	Broke at the opposite end to the preceding.
583	11087	67386			$27\frac{1}{2}$	Opposite end to the preceding.
591	11229	68093			26	Same end as the preceding.
595	11315	68523			22	Opposite end to the preceding.
595	11315	68660			$24\frac{1}{2}$	This exper. finished this part of the bar.
540	10260	62135			$0\frac{1}{2}$	Not heated. Piece broken off in first exp.
546	10374	63516			$5\frac{1}{3}$	Piece now in from 3 to $17\frac{1}{2}$. Part in tin from 8 to 12. Greatest wt. previously borne 336.
546	10374	62946			10	Broke in tin with the same weight as it bore in the preceding experiment.
582	11058	66987			$7\frac{1}{2}$	Part now tried from $5\frac{1}{3}$ to 10.
556	10574	64287			$10\frac{1}{2}$	Part now in from 10 to $17\frac{1}{2}$.
577	10973	66669			$15\frac{1}{2}$	Do. from $10\frac{1}{2}$ to $17\frac{1}{2}$.
577	10973	66757			$13\frac{1}{2}$	Do. " $10\frac{1}{2}$ to $15\frac{1}{2}$.
589	11201	68144			$12\frac{1}{2}$	Do. " $10\frac{1}{2}$ to $13\frac{1}{2}$.
						The mean area of 18 sections of fracture is .000011 square inch *greater* than that of the 31 measured sections.

TABLE LXXXV.

Experiments on bar No. 221 A. Manufactured by the Salisbury Iron Company, at Salisbury, in Connecticut. The ore obtained from "Ore Hill," in that town. The kind of metal *employed,* "white pig," *—refined after the English method. A loup made and a gun bar*

Marks.	Breadth.	Thickness.	Areas before trial.	No. of the exp't.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
1	.757	.224	.169568		1833.						
2	.752	.227	.170704	1	Mar. 14,	.170931	570.°	318	9540	477	9063
3	.754	.229	.172666								
4	.752	.228	.171456	2	"	.172060	580.	381	11430	571	10859
5	.753	.229	.172437								
6	.753	.229	.172437								
7	.753	.228	.171684	3	"	.171031	520.	362	10860	543	10317
8	.753	.228	.171684								
9	.753	.229	.172437								
10	.753	.229	.172437	4	"	.172186	73.	404	12120	606	11514
11	.753	.227	.170931								
12	.753	.227	.170931	5	"	.172437	72.	404	12120	606	11514
13	.752	.227	.170704								
14	.753	.228	.171684	6	"	.169947	71.5	404	12120	606	11514
15	.753	.228	.171684								
16	.753	.227	.170931	7	"	.171456	71.	404	12120	606	11514
17	.751	.228	.171228								
18	.752	.227	.170704	8	Mar. 16,	.170931	78.5	377	11310	565	10745
19	.753	.227	.170931								
20	.753	.227	.170931	9	"	.171684	78.	380	11400	570	10830
21	.753	.227	.170931								
22	.753	.227	.170931								
23	.753	.227	.170931	10	"	.170931	78.	380	11400	570	10830
24	.753	.228	.171684								
25	.753	.228	.171684								
$25\frac{6}{10}$	.752	.228	.171456	11	"	.170931	77.	392	11760	588	11172
Mean of 26=			.171376	12	"	.170817	77.	392	11760	588	11172
Maximum=			.172666	13	"	.170966	76.5	401	12030	601	11429
Minimum =			.169568								
				14	"	.179931	76.	394	11820	591	11229
Mn. of these 2			.171117								
					Mean of 14	.171231					
Diff. of the 2			.003098								

TABLE LXXXV.

formed expressly for these experiments. Drawn under the hammer, subsequently reduced by filing to a nearly uniform size, and gauged at every inch. Specific gravity, 7.8018.

Strength in lbs. per square inch.	Point of fracture.	REMARKS.
53021	No. 21	Part in tin from $2\frac{1}{2}$ to $5\frac{1}{2}$.
63111	" $8\frac{1}{2}$	Same part in tin. Temperature had been as high as 600° for a short time.
60322	" $13\frac{1}{3}$	Broke in tin. Part immersed from 13 to 16, inclusive. Had been strained in experiment No. 1. Temperature had been 550°.
66869	" $6\frac{1}{3}$	Part left in experiment 2d., which did not break *in tin.* Now broke at a part which was of a straw colour.
66772	" 5	Broke with the same weight as above.
67750	" $1\frac{1}{3}$	Bore the weight a moment, and then gave way.
67154	" 4	Bore the weight a short time.
62862	" $22\frac{3}{4}$	This part was broken off in experiment No. 1.
63081	" 25	Do.
63358	" 19	The weight is supposed to have been too great. The whole weight employed in the last experiment put on by mistake. The bar broke immediately.
65359	" 20	
65403	" $18\frac{1}{2}$	Gradually gave way under the same weight as the preceding.
66849	" $17\frac{1}{4}$	
65693	" $11\frac{1}{2}$	A different piece from the preceding.
		The mean area of the 14 sections of fracture is .000145 square inch *less* than that of the 26 measured sections.

TABLE LXXXVI.

Experiments on bar No. 221, B. Manufactured by the Salisbury Iron Company, at Salisbury in Connecticut. The ore obtained from "Ore Hill" in that town. "White pig" *metal, refined after the English method,—a loup formed and a "gun*

Marks.	Breadth.	Thickness.	Area at the sections measured before trial.		No. of the experiment.	DATE.	Area of the section of fracture before trial.	Temp. Fah.	Breaking wht. in the scale.	Breaking weight × leverage.	Friction.	Effective strain.
1	.762	.232	.176784			1833.						
2	.753	.229	.172437		1	Mar. 21,	.174347	57°6	335	10050	502	9548
3	.753	.229	.172437									
4	.753	.229	.172437		2	"	.173387	574	341	10230	511	9719
5	.754	.229	.172666									
6	.753	.230	.173190		3	"	.172437	576	378	11340	567	10773
7	.754	.231	.174174									
8	.755	.231	.174405									
9	.754	.229	.172666									
10	.755	.229	.172895		4	Mar. 23,	.173420	576	392	11760	583	11172
11	.755	.230	.173650									
12	.755	.230	.173650		5	"	.173420	576	402	12060	603	11457
13	.755	.230	.173650									
14	.754	.230	.173420									
15	.754	.230	.173420		6	"	.173928	100	410	12300	615	11685
16	.755	.230	.173650									
17	.755	.230	.173650									
18	.754	.230	.173420		7	"	.174289	90	416	12480	624	11856
19	.755	.230	.173650									
20	.756	.229	.173124		8	"	.173101	68	425	12750	637	12113
21	.755	.230	.173650									
22	.755	.231	.174405		9	"	.173147	68	425	12750	637	12113
23	.755	.231	.174405	Unfiled por-								
24	.754	.231	.174174	tion near the end.	10	"	.173650	68	425	12750	637	12113
25	.752	.232	.174464	Br. Th.								
25.6	.755	.232	.175160	.850 .227	11	"	.192950	68	392	11760	588	11172
Mean of 26			.173682									
					12	"	.173124	67	375	11250	562	10688
Maximum			.176784									
Minimum			.172437									
					13	"	.174812	66	375	11250	562	10688
Mean of the 2			.174610									
Diff. of the 2			.004347			Mn. of 12 =	.173589					

TABLE LXXXVI.

bar" drawn expressly for these experiments. Drawn under the hammer into two bars, each reduced by filing to a uniform size, and then marked and gauged at every inch. Specific gravity, 7.8018.

Strength in lbs. per sq. inch.	Point of fracture.	REMARKS.
54764	No. $23\frac{1}{4}$	Part in tin from 3 to $6\frac{1}{2}$.
56054	" $19\frac{1}{2}$	Same part still in tin.
62475	" 4	Took hold of the bar near the pan of melted metal, leaving a part for future experiment, and compelling it to break *in* or near the hottest part. Fracture *within the tin.*
64421	" 18	Part in tin from 12 to $15\frac{1}{2}$ which had been tried in the second experiment—fracture near the end.
66065	" $14\frac{1}{4}$	Broke *in the tin.*
67183	" $6\frac{3}{4}$	The part now put in is from 4 to 14, both ends of which have been broken in tin at 576°. Fracture took place outside of where it had been in the tin.
68025	" $7\frac{1}{2}$	Broke at a part which had been less heated than the preceding.
69976	" $8\frac{3}{4}$	Had not been in tin.
69958	" $10\frac{1}{3}$	Had been near the tin.
69755	" $11\frac{1}{2}$	Do. This part of the specimen is now finished.
57901	" unc.	Part now in the machine is from 1 to 4. The *unfiled part* being in the wedges, the fracture took place at that part.
61736	" 20	Short piece.—Had been between two former cold fractures in experiment second.
61140	" $25\frac{1}{3}$	This piece had likewise been tried only at a cold fracture in experiment first. No additional weight was required. The mean area of the 12 sections of fracture on the filed part was .000093 square inch *less* than that of the 26 measured sections.

TABLE LXXXVII.

Experiments on ar No. 222 A. Manufactured by the Salisbury Iron Company, at Salisbury in Connecticut. The ore obtained from "Ore Hill," in that town. The metal, a mixture of "dead gray," "lively gray," "mottled," and "white" pigs, refined after the English method, a loup formed and a gun bar drawn expressly for these experi-

Marks.	Breadth before trial.	Thickness before trial.	Areas of the measured sections before trial.	Marks.	Breadths after trial.	Thickness after trial.	Areas after trial.	No. of the experiment.	DATE.	Area of the section of fracture.	Temperature, Fahrenheit.	Breaking weight in the scale.
0	.766	.221	.169286									
1	.759	.219	.166221						1833.			
2	.759	.219	.166221					1	Mar. 21,	.168942	560°	294
3	.761	.218	.165898									
4	.762	.219	.166878									
5	.762	.220	.167640	Measures taken after the 4th experiment.								
6	.761	.221	.168181					2	"	.169286	73.5	350
7	.762	.222	.169164	1	.728	.209	.152252					
8	.764	.222	.169608	2	.735	.207	.162145					
9	.762	.222	.169164	3	.730	.209	.152570					
10	.762	.222	.169164	4	.726	.207	.150282	3	"	.169164	73.5	360
11	.759	.222	.168498	5	.694	.196	.136024					
12	.761	.222	.168942	6	.690	.200	.138000	4	"	.168942	73	367
13	.761	.222	.168942	6½	.675	.193	.130275					
14	.762	.222	.169164	7	.690	.199	.137310	5	"	.168402	572	348
15	.763	.222	.169386	8	.731	.207	.151317					
16	.762	.222	.169164	9	.725	.210	.152250	6	Mar. 23,	.169164	75	377
17	.761	.222	.168942	10	.730	.210	.153300					
18	.761	.222	.168942	11	.730	.211	.154030	7	"	.168942	75	377
19	.761	.222	.168942	12	.720	.206	.148320					
20	.762	.221	.168402					8	"	.168181	75	377
21	.761	.222	.168942					9	"	.167497	75	377
22	.762	.222	.169164					10	"	.169164	75	377
23	.762	.221	.168402					11	"	.168942	67	374
24	.762	.220	.167640					12	"	.168402	67	374
25	.761	.221	.168181					13	"	.168046	67	374
26	.762	.221	.168402									
27	.762	.221	.168402					14		.168497	67	374
27½	.762	.221	.168402									
Mean of 29			.168420					15		.168737	67	378
Maximum			.169608						Mean of 15	.168686		
Minimum			.165895									
Mean of the 2			.167751									
Diff. of the 2			.003713									

TABLE LXXXVII.

ments. Drawn into two bars (A & B.) Reduced to a uniform size by filing, gauged at every inch from 0 to 27½, inclusive. Specific gravity, 7.7555.

Breaking weight × leverage.	Friction.	Effective strain.	Strength in lbs. per square inch.	Point of fracture.	REMARKS.
8820	441	8379	49597	No. 17	Part in tin from 4 to 8. Temperature rose once above 650°.
10500	525	9975	58924	0	The temperature rose to 660° when the bar appeared to be breaking. Having allowed the temperature to abate until it descended to 575°. Added weights until it appeared to be again breaking with 335 lbs. in the scale. Some tin then escaped at the packing, and 15 lbs. more were required to break it when cold.
10800	540	10260	60651	14	
11010	550	10460	61915	12½	
10440	522	9918	58895	27¼	Part in tin from 21 to 24½.
11310	565	10745	63518	7	Part under trial from 1 to 12.
11310	565	10745	63602	10⅓	Section of fracture gauged after this experiment, $.586 \times .153 = .089658$.
11310	565	10745	63889	6	
11310	565	10745	64150	4½	
11310	565	10745	63518	9¼	
11220	561	10659	63092	18½	
11220	561	10659	63295	26	
11220	561	10659	63429	24¾	
11220	561	10659	63259	22⅞	
11340	567	10773	63851	20⅝	The mean area of 15 sections of fracture, is *less* than that of 29 measured sections by .000266 square inch.

TABLE LXXXVIII.

Experiments on bar No. 222 B. Manufactured by the Salisbury Iron Company, at Salisbury, in Connecticut. The ore obtained from "Ore Hill," in that town. The metal was a mixture of "dead gray," "lively gray," "mottled," and "white" pig. Refined after the Eng-

Marks.	Breadth.	Thickness.	Areas of measured sections before trial.	No. of the experim't.	DATE.	Area of the section of fracture before trial.	Temperature, Fah.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.
0	.752	.217	.163184		1833.					
1	.757	.217	.164269	1	Mar. 28,	.166100	560.°	298	8940	447
2	.757	.218	.165026							
3	.757	.219	.165783	2	"	.163455	576.	308	9240	462
4	.757	.219	.165783							
5	.756	.219	.165564	3	"	.166100	566.	320	9600	480
6	.755	.217	.163835							
7	.754	.216	.162864	4	"	.166320	554.	348	10440	522
8	.754	.217	.163618							
9	.755	.219	.165345	5	Mar. 30,	.163241	566.	349	10470	523
10	.755	.219	.165345							
11	.757	.220	.166540	6	"	.163998	66.	349	10470	523
12	.757	.220	.166540							
13	.756	.221	.167076	7	"	.162864	66.	374	11220	561
14	.756	.220	.166320							
15	.756	.220	.166320	8	"	.165026	65.	374	11220	561
16	.756	.220	.166320							
17	.755	.220	.166100	9	"	.164267	65.	375	11250	562
18	.755	.220	.166100							
19	.755	.220	.166100	10	"	.165783	65.	375	11250	562
20	.755	.220	.166100							
21	.754	.218	.164372	11	"	.166100	554.	332	9960	498
22	.754	.218	.164372							
23	.754	.218	.164372	12	"	.165816	578.	345	10350	517
24	.756	.219	.165564							
25	.756	.220	.166320	13	"	.167076	64.	369	11070	553
26	.756	.220	.166320							
27	.756	.220	.166320	14	"	.166540	64.5	370	11200	555
27.7	.756	.219	.165564							
				15	April. 4,	.165753	75.5	374	11220	561
		Mean of 29	.165425							
				16	"	.165236	74.	369	11070	553
		Maximum	.167076							
		Minimum	.162864	17	"	.164372	74.	369	11070	553
		Mean of these 2	.164970		Mean of 17	.165178				
		Diff. of the 2	.004212							

TABLE LXXXVIII.

lish method. A loup formed and a gun bar drawn, expressly for these experiments. Reduced to a nearly uniform size by filing, and gauged at every inch from 0 to 27.7. Specific gravity, 7.7555.

Effective strain.	Strength in lbs. per square inch.	Point fractured.	REMARKS.
8493	51132	No. 18½	Part in tin from 5½ to 9.
8778	53703	" 0¼	Broke near the wedges.
9120	54907	" 17⅓	Broke near the wedges on the opposite side of tin bath.
9918	59632	" 15⅓	Do.
9947	60934	" 7½	Broke in the tin.
9947	60653	" 0¾	
10659	65447	" 7	Cut off the tinned part in the gripe of the wedges.
10659	64589	" 2	
10688	65064	" 5¾	
10688	64469	" 3⅞	
9462	56966	" 20	Part in tin from 22¼ to 25½.
9833	59301	" 24⅓	Broke *in tin.* Temp. had been as high as 614°.
10517	62947	" 13	This part not heated.
10545	63318	" 11	
10659	64389	" 24¼	Part now under trial from 20 to 24⅓.
10517	63649	" 20½	
10517	63983	" 21½	
			The mean area of the 17 sections of fracture is .000247 square inch *less* than that of the 29 measured sections.

TABLE LXXXIX.

Comparative view of the influence of high temperatures on the strength of iron, as exhibited by 73 experiments on 47 different specimens of that metal, at 46 different temperatures, from

No. of the comparison	Temperature observed at the moment of frac.	Mark of the bar on which the trial was made.	Strength at ordinary temperatures.	No. of experiments at ordinary temperatures.	Strength at the temperature observed.	No. of experiments at high temperatures.	Amount of variation from uniformity in the cold experiments.	Effects of the heat expressed in parts of the original strength.	REMARKS.
1	212°	137	56736	1	67939	1		+ .197	
2	214	133	53176	1	61161	1		+ .150	
3	394	58	68356	1	71896	1		+ .052	
4	394	148	65143	1	69752	1		+ .070	
5	394	23	62646	2	67765	1	.1041	+ .081	
6	394	125	57182	1	63322	1		+ .107	
7	394	61	55297	5	61917	1	.2026	+ .119	
8	396	75	60433	3	62415	1	.0444	+ .031	
9	440	224D.	49782	4	59085	1	.0908	+ .187	
10	520	224B.	54934	4	58451	1	.0992	+ .064	
11	550	199A.	76986	4	79846	2	.0936	+ .037	The standard for the
12	550	221A.	60518	4	60322	1	.1680	— .004	original strength may
13	552	14	52542	1	55932	1		+ .064	possibly be a little too
14	554	218A.	58124	4	60412	1	.0730	+ .039	high.
15	554	22	54372	4	61680	3	.1919	+ .134	
16	560	224E.	50528	7	58824	1	.0605	+ .158	
17	562	224C.	53385	5	59623	1	.1919	+ .104	
18	563	60	60907	4	72588	2	.0460	+ .191	
19	564	74	51030	5	58284	1	.0764	+ .142	
20	568	9	67211	2	76763	1	.0601	+ .042	Standard probably
21	572	219B.	66724	2	66620	1	.0325	— .002	too high for the mean
22	572	49	59607	3	62278	1	.0878	+ .045	strength.
23	572	222B.	56165	4	60117	2	.1550	+ .070	
24	573	10	64511	1	67503	3		+ .046	
25	574	231	76071	5	65387	1	.1373	+ .014	
26	575	220A.	54263	4	60988	1	.0280	+ .124	
27	575	62	58376	3	70081	3	.0262	+ .200	
28	575	207	51924	5	63825	3	.1225	+ .229	
29	576	221B.	59234	5	66065	1	.1190	+ .115	
30	576	223B.	43386	6	50068	1	.0760	+ .154	

TABLE LXXXIX.

212° to 1317° Fah., compared with the strength of each bar when tried at ordinary temperatures, the whole number of experiments at the latter being 163.

No. of the comparison.	Temperature observed at the moment of frac.	Mark of the bar on which the trial was made.	Strength at ordinary temperature.	No. of exp. at ord. temp.	Strength at the temperature observed.	No. of exp. at high temp.	Amount of variation from uniformity in the cold experiments.	Effects of the heat in parts of the original strength.	REMARKS.
31	°577	164	58769	5	66929	2	.1214	+.139	
32	578	224A.	52406	5	59197	1	.0565	+.129	
33	578	223A.	45757	5	53465	1	.0896	+.168	
34	580	86	62156	3	77163	2	.0986	+.052	
35	590	220B.	59459	5	62966	1	.0680	+.058	
36	598	90	50316	5	57310	2	.2401	+.138	
37	630	219A	59530	4	60010	1	.1440	+.008	
38	636	16	53543	1	50039	1	.1563	—.067	This experiment was on a part probably defective.
39	662	150	59307	5	58181	1	.0644	—.019	
40	722	152	57133	3	54441	1	.0507	—.047	
41	732	14	52542	1	53378	1	.1310	+.016	
22	734	150	59397	1	57903	1	.0644	—.026	
43	766	16	56891	1	54819	1	.1563	—.037	
44	770	149	56825	2	54781	1	.0234	—.036	
45	824 and 814	214	59219	1	55892	1	.0413	—.073	
46	825	149	56825	2	56644	1	.0234	--.029	
47	932	214	59219	1	45531	1	.0413	—.240	
78	947	232	58341	2	42401	1	.0446	—.273	
49	1022	214	59219	2	37410	1	.0413	—.369	
50	1037	152	58992	1	37764	1	.0507	—.360	
51	1097	227	53426	6	27604	1	.0330	—.483	
52	1111	227	53426	6	27602	1	.0330	—.483	
53	1142	226	54758	2	18672	1	.1147	—.659	The metal was decidedly defective at the point where this fracture was made—flaws visible.
54	1155	227	53426	6	21967	1	.0330	—.589	
55	1159	229	55774	3	25620	1	.1102	—.538	The 8th experiment on this bar being taken as the standard would exhibit the effect—.550.
56	1187	227	53426	6	21910	1	.0330	—.589	
57	1235	226	54758	2	21298	1	.1147	—.611	
58	1245	226	54758	2	20703	1	.1147	—.622	
59	1317	226	54758	2	18913	1	.1147	—.654	
		Mean	57525						

Effect of high temperature on iron.

The experiments on bars of iron at high temperatures, were made either on sections deeply filed, or on those specimens which had been reduced by filing to a uniform size.

The trials below 600° were chiefly conducted in a bath of oil, arranged round the bar as already represented in Plates III. and IV., and the temperatures marked by the mercurial thermometer. For temperatures above that point the bath of tin and lead was substituted, and, when necessary, the steam pyrometer took the place of the common thermometer.

The view already presented of the influence of heat on copper, indicated partly by each of these two instruments, has enabled us to observe that they connect themselves in their indications in a manner to prove that no serious errors can be anticipated in the temperatures assigned in the higher parts of the scale when operating on iron.

If, however, in examining the effect of temperature on copper we meet with some difficulties in consequence of the irregularities of structure in the material, of want of conformity in different bars, and of the occasional weakening effects of alloying, on the total tenacity as we approach a red heat, the obstacles there encountered are comparatively trifling, when contrasted with those which are to be surmounted in the investigation of the effects of heat upon the tenacity of iron. Here we have, not only the variations due to the original composition of the metal; the differences resulting from the variety of pig-metal used in its manufacture, and the defects of the mechanical structure, owing to the want of uniformity in welding, or of regularity in the temperature of working the bars; but we have superadded to all these, a singular anomaly in the effect of heat itself on the tenacity of this material, which is believed never to have been before made the object of special inquiry.

Notwithstanding these impediments, the committee have not felt authorized to leave so important a point of inquiry, without a faithful attempt to unravel its intricacies. It would have been easy to devise a set of experiments, which, for a theoretical purpose, might have afforded to the analyst some interesting problems, and probably served to clear the subject of heat from certain difficulties with which its investigation is encumbered. Such, however, was not the purpose in view of the committee.

When we attempt to form a scale of the weakening effects of elevated temperatures, founded, as in the case of copper, on trials at ordinary temperatures, or even at the freezing point, we shall find that many of the first numbers in the scale will be negative, instead of positive, and this will continue to different points of temperature, according to the nature or condition of the iron on which the experiments are made. In fact, some of the very first experiments at high temperatures rendered this manifest, by showing that on a bar of uniform size, the fracture would not take place within the heating bath; and even that *much* filing of the part in the oil or melted metal, was necessary in order to prevent the fracture from taking place at unfiled sections *out of the hot bath* rather than at the filed one in it. This circumstance was noted at 212°, 392°, and 572°, rising by steps of 180° each from 32°, at which last point some trials had been made in melting ice. At the highest of these points, however, it was perceived that some specimens of the metal exhibited but little, if any, superiority of strength over that which they had possessed when cold, while others allowed of being heated

nearly to the boiling point of mercury before they manifested any decided indication of a weakening effect from increase of temperature.

It hence became apparent that any law, taking for a basis the strength of iron in its ordinary condition, and at common temperatures, must be liable to great uncertainty, in regard to its application to different specimens of the metal. It was evident that the anomaly above referred to, must be only apparent, and that the tenacity actually exhibited at 572°, as well as that which prevails while the iron is in the state in which it was left by forging, or rolling, must be below its maximum tenacity. To determine what ratio exists between the ordinary strength of a bar and its maximum strength when in the most favourable condition for resisting a longitudinal strain, experiments were made on several bars by heating them to 572°, and then applying weight enough to cause a fracture, either within or without the heated part. The bar was then taken out and allowed to cool, when the strength which was obtained on parts influenced by the heat became a standard of comparison for experiments at more elevated temperatures. A mean of thirty-five comparisons, conducted in the manner just described, afforded a standard 16.2 per cent. greater than the ordinary strength of the metal; but the standard most relied on for furnishing the basis of calculations, and for determining a law of diminution of tenacity, was derived from the five varieties of iron, manufactured by the Salisbury Iron Company, which, being of a tolerably uniform texture, were considered rather more suitable than others for supplying the ground work of a law for calculating the effect of temperature on this metal generally. An examination of the trials on those bars will be found to furnish a standard of maximum tenacity 15.17 per cent. greater than their mean strength when tried cold. When, however, an unexceptionable standard was given by any bar after trial at 572° and subsequent cooling off, its own standard for increased strength was used in computing the true effect of heat at other high temperatures.

Thus, at a temperature of 1317°, the bar No. 226, which had possessed, when cold, a strength of 54758 lbs., gave a remaining strength of only 18913 lbs. Now, 54758 lbs. increased 15.17 of itself, gives 63065, and from this deducting 18913 we have 44152 lbs. for the *diminution* of its absolute tenacity by the temperature just mentioned, or .7001 of the maximum strength.

On the same bar, (No. 226,) were made at different points, two other experiments with the same weight each time in the scale.

The first of these sections gave way when the temperature had reached 1237°. The strength per square inch given in this case was 21298, and comparing this with the maximum strength, 63065, we obtain 41767 as the diminution, equal to .6622 of that maximum.

The second trial on a larger area of section required a higher temperature to cause the fracture to take place under the given weight, viz: 1245°, giving at this temperature a tenacity of 20703 lbs., and by the same computation showing a diminution from the maximum 63065 of .6715. Both of these trials having been made with the precaution of raising and lowering the suspended furnace, to regulate the heat, it is believed that no essential error in regard to temperature can have existed. The first was conjectured to be, if anything, a trifle in excess.

If we take the mean of these two results, viz. .6668 for the diminution of tenacity at 1241° the mean temperature, it cannot vary far from the true

effect. On bar 227 an experiment was made at 1187°, giving a tenacity of 21913 lbs. per square inch. Within two and a half inches of the same point a cold fracture gave a strength of 52186 lbs., from which the calculated maximum is 60102, and the diminution is 60102—21913, or 38189; which is .6352 of the same maximum tenacity.

On No. 229 was made an experiment at 1159°, which exhibited a tenacity of 25620 lbs. Three experiments on the same bar when cold, gave a mean strength of 55774 lbs. Hence 55774×.1517=8460; and (55774 +8460)—25620=38614, which is .6011 of the maximum tenacity.

On No. 227 we have an experiment at 1155°, giving a tenacity of 21967, and the four cold experiments nearest to the same point give a mean of 47749, from which we obtain the maximum 54992, and the diminution = .6000.

On No. 226 was made an experiment at 1142°, but as the iron at the part in which the fracture took place was defective from flaws, and had probably been impaired by the previous straining of the bar, it was not considered necessary to attempt to reduce its apparent tenacity to the standard, being entirely anomalous.

At 1111° the bar No. 227 had a strength of 27602, and another trial on the same at 1097°, 27602.

The weight in the scale was the same in both cases, and the temperatures would probably have been the same, had not the standard piece in the latter case accidentally risen above the melted lead a short distance just before the fracture. Taking the mean of these two results 27603, for the strength at 1111°, and the mean of six trials on this bar near the two points where these fractures occurred, viz: 53426, we obtain the maximum tenacity at those points 61531, and the diminution by heat .5614.

On bar 152 an experiment at 1037° gave a tenacity of 37764, and on No. 214 an experiment at 1022° gave 37410. The mean cold strength of these two bars was 59105, from which we deduce the maximum 68071; and the diminution for the mean temperature 1030°, equal to .4478 of the maximum.

At 947° an experiment on bar No. 232 gave a strength of 42401, the mean of the two experiments subsequently made nearest to this point gives the experimental maximum strength 66193 from which the diminution is .3593.

At 932° bar No. 214 had a tenacity of 45531, while its cold strength was 59319, and its maximum 68202, hence the diminution is .3324.

An experiment was made on bar 149 at a temperature marked 825°, but as the furnace was not lowered during the performance of it, and as the time during which the bar continued to stretch after the strength had been fairly overcome, was considerable, the temperature is in all probability too high; and the experiment is not considered comparable with the rest of the series.

In bar No. 214, at the temperature of 824°, the remaining strength was 55892, the original strength, 60850, and the maximum by calculation, 70080, whence the diminution is .2010.

On bar 149 was an experiment at 770°, giving a tenacity of 54781; while the original strength was 56825, and the diminution from the calculated maximum .1627.

On No. 16 we find an experiment at 766°, giving 54819. Two subsequent experiments yielded maxima, the mean of which is 65176, whence the diminution is .1586.

In bar No. 150, a temperature of 734°, left a strength of 57903. The first experiment on the bar afforded 59397, from which we calculate the maximum 68407, which proves the diminution at this temperature to be .1535.

On No. 14 we obtained a strength of 53378, at 732°, and the mean of three experimental maxima, is 62736, hence the diminution by heat is .1491.

On No. 152 we had at 722° a tenacity of 54442, and three experiments gave a *cold strength* of 55990, from which a calculated maximum of 64483 is obtained, and consequently a diminution of .1557. But an experimental maximum of 62709 was obtained on this bar, which on account of the remoteness of the point where it occurred, from the point on which the hot fracture was made, is believed to be rather too low. Calculating, however, from this maximum, we find the diminution .1316.

If we take the mean of the two results, .1557 and .1316, we have the probable diminution from the true maximum, .1436.

On No. 150 we find an experiment at 662°, giving a tenacity of 58182. On the same bar an experimental maximum was found of 65785, from which we get the diminution equal to .1155.

On No. 16 was made a trial at 636°, yielding a result of 50039, a result far lower than that given afterwards on the same bar at 766°; we are therefore compelled to believe that this experiment was made on a defective part of the bar.

On No. 219 A, was a trial at 630°, which exhibited a tenacity of 60010. An experiment subsequently made within 1⅜ inches of the same point, gave a tenacity of 67033, and consequently the diminution is .1047.

On No. 90 an experiment at 600° gave a tenacity of 56938, and three experiments on the same bar, when cold, gave a mean of 54715, from which the calculated maximum is 63015, and the diminution .0964.

On the same bar (No. 90,) another trial took place at 596°, giving a strength of 57682 lbs., and if we assume the original strength of this section equal to that given by the third experiment on the same bar, 55037, we shall have the maximum by calculation 63386, and the diminution .0899.

By a mean of 5 sets of experimental maxima derived from 65 trials on the 5 varieties of Salisbury iron we have a standard of 66146. The six trials at the mean temperature of 570° referred to in our remarks in Table LXXIX. of the effect of employing different kinds of pig-metal, show that at a mean temperature of 570° those trials gave a strength of 60398 lbs., whence the diminution is .0869.

Of 224 B, at 520° the tenacity was 58451. On the same bar, four cold experiments gave a mean strength of 54934, which by calculation gives a maximum of 63267 and a consequent diminution of .0761.

On a survey of the preceding discussions it will be seen that in determining the maximum belonging to each point of fracture, it has been necessary to resort sometimes to experimental, and sometimes to calculated results, but that in several cases the two operate as checks upon each other.

On attempting to extend the principle to trials made below the temperatures already cited, we are liable to encounter an ambiguity in the results, owing to the fact that the maximum tenacity is not generally to be obtained without having carried the previous temperatures to about 550° or 600°, and the tension to nearly or quite that of the original strength of the metal when cold.

In projecting into a curve as in Plate X. the data furnished by the experiments above described, and of which a synopsis is given in the following table, it becomes at once apparent that what was *conjectured* with respect to copper, in regard to a point of inflection, is here presented in a manner to admit of no uncertainty. Indeed it could hardly be otherwise, when we consider that the melting point of wrought iron, at which all tenacity must be overcome, is doubtless situated above 3000° ; and by the experiments of Clement and Desormes, is as high as 3945°. Now it appears that at a temperature no higher than about 1050° one-half of the strength is destroyed ; at 1240°, two-thirds ; and at 1317°, seven-tenths of the maximum tenacity is overcome.

The following table exhibits the observed temperatures, and corresponding tenacity of the metal with the calculated, or experimental maximum of strength,—the ratio of the observed diminution to the maximum tenacity, and the irregularity of the metal in parts of the original strength at ordinary temperatures.

TABLE XC.

No. of the comparison.	Marks of the bar.	Temperature observed.	Tenacity observed.	Maximum tenacity at the point of fracture.	Manner in which the maximum was obtained.	Diminution by heat in parts of the maximum tenacity.	Irregularity of the metal in parts of the original strength.
1	224 B.	520°	58451	63275	Experiment.	.0738	.0992
2	Salisb. iron.	570	60398	60398	do.	.0869	.1125
3	90	596	57682	57682	Calculation.	.0899	.2401
4	90	600	56938	63086	do.	.0964	.2401
5	219 A.	630	60010	67033	Experiment.	.1047	.1440
6	150	662	58182	65785	do.	.1155	.0644
7	152	722	54442	64483	Calculation.	.1436	.0507
8	14	732	53378	62736	Experiment.	.1491	.1310
9	150	734	57903	68407	Calculation.	.1535	.0644
10	16	766	54819	65176	Experiment.	.1589	.1563
11	149	770	54781	65445	Calculation.	.1627	.0234
12	214	824	55892	70080	do.	.2010	.0413
12	214	932	45531	68202	do.	.3324	.0413
14	232	947	42401	66193	Experiment.	.3593	.0446
15	{214 / 152}	1030	37587	68071	Calculation.	.4478	.0460
16	227	1111	27603	61531	do.	.5514	.0330
17	227	1155	21967	54992	do.	.6000	.0330
18	229	1159	25620	64234	do.	.6011	.1102
19	227	1187	21913	60102	do.	.6352	.0330
20	226	1237	21298	63065	do.	.6622	.1147
21	226	1245	20703	63065	do.	.6715	.1147
22	226	1317	18913	63065	do.	.7001	.1147

From the eighth column of the preceding table it appears that of these 15 different specimens of iron, the mean irregularity of structure is 10 per cent. of the mean strength when tried cold.

For the purpose of ascertaining, approximately, the law of decrease in strength by temperature, an investigation was made similar to that adopted for copper, embracing, however, only 12 of the points contained in the preceding table.

As some of the experiments which furnished the standards of comparison for strength at ordinary temperatures, were made at 80°, and as at that point small variations in respect to heat appear to affect but very slightly the tenacity of iron, it was conceived that for practical purposes at least, the calculations might be commenced from that point.

Eighty degrees are therefore deducted from each temperature in the following table, and the remainders used, instead of the numbers commencing from the 0 of our scale. It will be found that with the exception of a slight anomaly between 520° and 570°, amounting to —.08, the numbers expressing the ratio between the elevations of temperature, and the diminutions of tenacity, constantly increase until we reach 932°, at which it is 2.97, and that from this point the ratio of diminution decreases to the limits of our range of trials, 1317°, where it is 2.14. It will also be observed, that the diminution of tenacity at 932°, where the law changes from an increasing to a decreasing rate of dimiuution, is almost precisely one-third of the total, or *maximum* strength, of the iron at ordinary temperatures.

At this point it will be seen, the curve traced in the figure, Plate X., undergoes an inflection, and in all probability continues in the same general direction to the fusing point.

TABLE XCI.

No. of the comparison.	Observed temperatures.	Observed temperatures —80°.	Observed diminution of tenacity.	Power of the temperature which represents the diminution of tenacity at each point.	REMARKS.
1	520°	440°	.0738	2.25	
2	570	490	.0869	2.17	
3	596	516	.0899	2.38	
4	662	582	.1155	2.67	
5	770	690	.1627	2.85	
6	824	744	.2010	2.94	
7	932	852	.3324	2.97	Point of inflection near this temperature.
8	1030	950	.4478	2.92	
9	1111	1031	.5514	2.63	
10	1155	1075	.6000	2.60	
11	1237	1157	.6622	2.41	
12	1317	1237	.7001	2.14	
			Mean	2.58	

From the above table it appears that the ratio of diminution furnished by a comparison of some of the lower temperatures with all those above them is higher than the duplicate. The same inference is derived from a comparison of the higher members of the series with all those below them.

At 932° it will be seen that a comparison with all those both above and below that temperature, gives a rate very nearly approaching to the cube. The particular comparison between 824° and 932° gives a rate higher than the 4th power, viz. 4.08.

Hence though the diversity of the metals operated on, is such as not readily to furnish the precise mathematical law, it is still abundantly apparent that this law must be different from that which is indicated by any one of the family of parabolas.*

But for practical purposes the table indicates, by the *mean* of all the rates, that a rule may be followed, not widely different from what is represented by saying that the *thirteenth power of the temperature above* 80° *is proportionate to the* 5*th power of the diminution from the maximum tenacity*.†

Plate X. exhibits at .1517, in the line of observed diminution, the commencement of a branch of the curve descending to the right, which indicates the progressive effects of temperature, increasing, as it rises, the tenacity of iron until a certain point is reached, when the weakening influence begins to be felt. The other branch of the curve, or that which takes its rise from the origin of the abscissas, forms, with the first, a cusp of peculiar character at a point c, which, however, the experiments are not sufficiently numerous in this part of the scale to determine exactly in respect to *position*.

From the preceding discussion Table LXXXIX. will be sufficiently intelligible without further comment.

Elasticity of Iron.

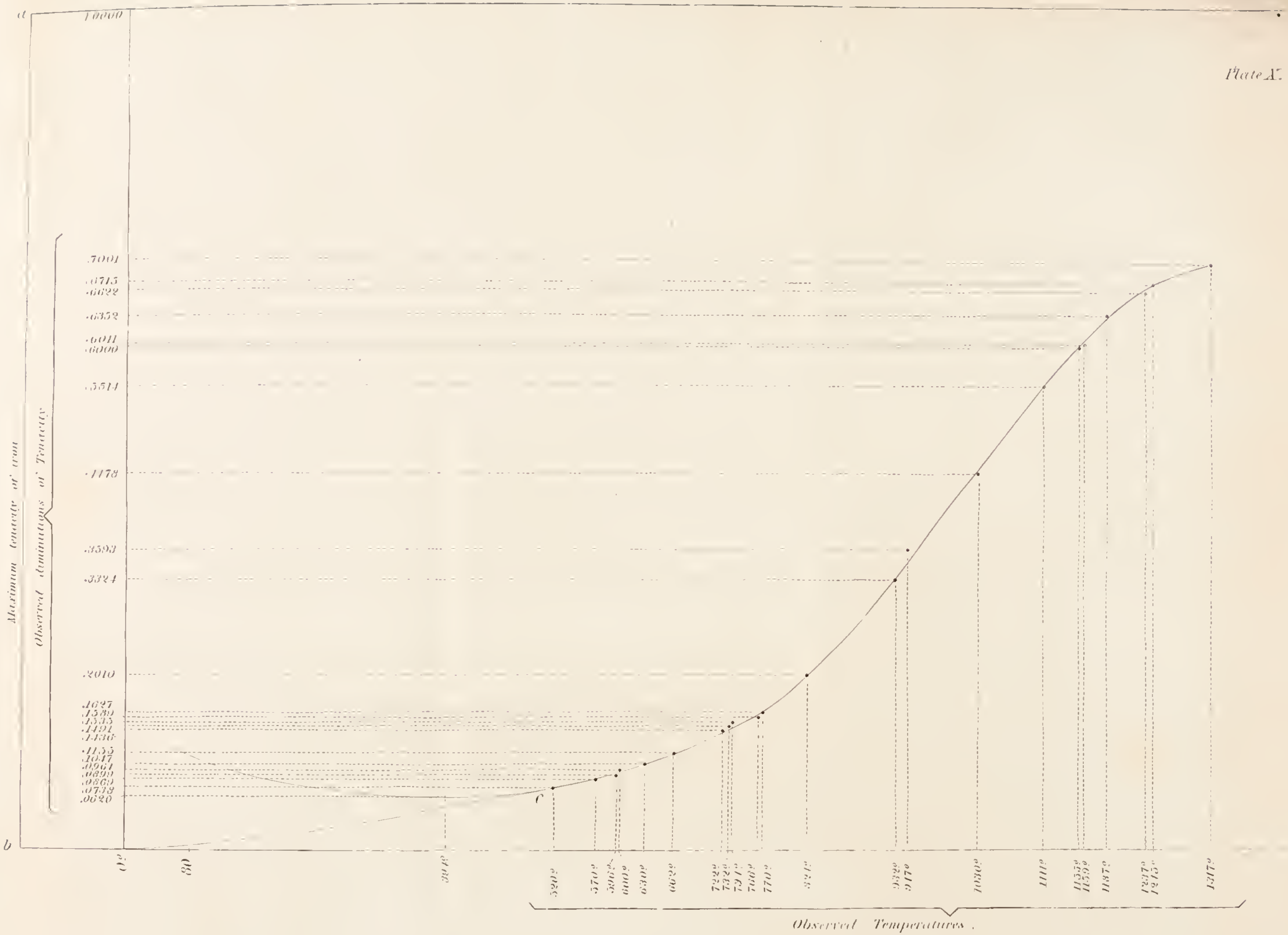
In describing the method of determining the elasticity of the *machine* for tenacities, we have given in effect a detail of the processes also pursued with the bars of iron generally.

The strong bar then interposed between the heads, b', b'', (Plate I.) was, however, now replaced by the specimen under trial, and as the machine was capable of overcoming the total strength of each specimen, the temporary elongations, as well before as after the bar had begun to be permanently extended, were easily deducible from the observed elasticity of the *bar and of the machine together*, corrected by deducting the already ascertained elasticity of the machine alone.

* Represented by the well known géneral formula, $y^q = mx^p$.

† It is evident from what has already been said, that if we would *calculate* the reduction from the ordinary strength of iron as it comes from the hammer or the rolls, we must first reduce it to the maximum, by adding to its observed strength at a known low temperature, 15.17 per cent. of itself. It is, moreover, apparent from the curve, as well as from the table, that if we conceive the ordinates (y) or increments of temperature, and the abscissas (x) or decrements of tenacity to be drawn from any two points *below* 932°, the increase (dx) of any abscissa, for the contemporaneous increase (dy) of the corresponding ordinate, will observe an *increasing rate;* but *above* that point where also the *differential co-efficient* $\frac{dy}{dx}$, is a maximum, and where the *differential co-efficient of the second order* $\frac{d^2y}{dx^2}=0$, they observe a decreasing rate and the concavity of the curve is accordingly directed towards the axis of the abscissas, in place of the convexity which had hitherto inclined in that direction.

Plate X.


Maximum tenacity of iron
Observed diminutions of Tenacity
1.0000
.7001
.6715
.6622
.6352
.6011
.6000
.5514
.4478
.3593
.3324
.2010
.1627
.1580
.1535
.1491
.1436
.1155
.1047
.0964
.0899
.0869
.0738
.0620
Observed Temperatures.

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By referring to a former part of this report (Table III.) there will be found a series of numbers corresponding to the several observed elasticities of the machine, used by the committee, and representing in inches the actual distances, or quantities of recoil after the strain had been removed. From those numbers may be taken out *by inspection*, the quantity of recoil for each trial in the following table, and comparing the results thus obtained with the total lengths of the bars, it will be seen by what part of its whole length, each was elongated and contracted at every trial.

It will not fail to be remarked that in the more extended series of the table, those for example, in which 7 or 8 trials were made on the same bar, the maximum of elasticity was often found within a comparatively small number of pounds of the *breaking weight*, and that it was seldom so low as two-thirds of that weight. This is at variance with the supposition that the elasticity of a bar is destroyed or much diminished at the moment it has begun to be permanently elongated.

Second method of observing elasticities.

Another method of approximately determining the elasticity of iron as indicated when subjected to different strains, was to measure directly on the specimen under trial the distance between two points, taken as remote from each other as possible, both when under strain and when that strain was removed.

Thus bar No. 49 having been permanently elongated $\frac{3}{10}$ of an inch, in $20\frac{3}{10}$, under a weight of 273 pounds in the scale, gave a recoil of .05 of an inch. Afterwards with a weight of 301 lbs., and when a permanent elongation of .58 inch, in the same original length had taken place, the recoil amounted to $\frac{1}{348}$ of the total length. After that trial 15 pounds in addition were required to break the bar.

On bar 226 the first permanent elongation was found under a weight of 245 pounds. Under a weight of 280 pounds the elongation in 24 inches was .86 inch, and when relieved it was .82, giving a recoil of .04 in 24 inches,$=\frac{1}{600}$.

After this last trial 35 pounds additional weight were required to produce the fracture.

On bar 228, we find that the first elongation was taken under a weight of 232 pounds. With 238 pounds it had become .146 inch on a length of 24; but when relieved the recoil was .046 inch, equal to $\frac{1}{525}$ of the length. Twenty-eight pounds were afterwards required to be added to break the bar.

On bar 230 the elongation took place under 196 pounds. With 317 pounds the recoil on a part originally 24 inches long was .05 inch, equal to $\frac{1}{450}$ of the whole original length, and 13 pounds more were required to produce the fracture.

Experiments and remarks on this subject will be found in Tables XXXVII., XL., LV., LIX., &c.

TABLE XCII.—*Synopsis of the elasticity of 56 different bars of iron of given lengths, under certain weights, and also the breaking weights of the same bars as found immediately subsequent to the*

No. of the bar and direction of the slit.	Length under trial.	Weight in the scale.	Elasticity observ. corrected for the machin.	No. of the bar & direc. of the slit.	Length under trial.	Weight in the scale.	Elasti. observed correct. for the machine.	No. of bar & direction of the slit.	Length under trial.	Weight in the scale.	Elastic. observed correct. for the machine.
2.	23.55	280	15′	39. C.	23.5	224	20′			452	Broke.
L'gth.		336	16			314	31	58. C.	22.35	448	26′
		392	19			317	Broke.			479	Broke.
		448	25	41. L.	23.35	224	45	58. C.	20.7	479	57
		474	21.5			282	27.5			496	Broke.
		479	Broke.			292	Broke.	59. L.	23.5	112	12.5
4. L.	13.2	224	35	42. L.	23.8	224	27			168	20
		336	38			336	32			224	27
		448	16			399	28.5			242	27
		460	Broke.			427	31			258	Broke.
8.	21.2	280	20			443	Broke.	61. L.	23.6	224	40
Cross.		336	22	42. L.	22.45	399	28.5			280	42
		392	15			427	31			326	38
		430	15			452	Broke.			332	36
		443	Broke.	42. L.	18.8	399	28.5			336	Broke.
17. Cr.	23.9	259	23			462	22	68. L.	24.	224	32
		280	22			462	Broke.			336	31
		294	14	44. L.	23.7	224	25			392	28
		326	17.5			336	25			414	30
		336	21			448	23			441	32
		350	24			476	36			450	Broke.
		364	31.5			496	34	68. L.	20.8	224	32
		371	27			503	Broke.			448	20
		374	Broke.	46. L.	24.4	224	29			455	Broke.
18. Cr.	Unc.	392	32			280	29	70. L.	24.2	112	19.5
		403	37.5			297	28.5			224	16
		412	39			314	Broke.			280	19
		415	26	48. L.	24.5	224	16			336	23
		415	Broke.			336	18			364	26
21. L.	17.4	280	25			425	21.5			377	Broke.
		321	26.5			444	30	64. C.	24.2	112	38
		336	28			464	27			224	55
		356	Broke.			478	31			280	51.5
23. L.	24.3	280	21			487	28			301	52.5
		364	31			503	Broke.			329	46
		393	Broke.	51. C.	24.	224	53			335	Broke.
23. L.	21.1	280	29			336	53	65. C.	24.25	224	19
		364	22			448	27			280	18
		413	57			464	32			336	27
		426	Broke.			472	Broke.			369	Broke.
25. L.	24.1	224	39	53. C.	24.	224	37	71. C.	24.1	224	20
		361	28.5			336	36			336	27
		370	Broke.			448	21			357	Broke.
27. L.	24.2	224	35			464	22	71. C.	23.1	336	28
		336	38			478	Broke.			392	26
		392	53	53.	21.	494	25			414	Broke.
		403	Broke.			500	Broke.	73. C.	23.95	112	5.5
32. Cr.	23.	112	10.5	56. C.	23.7	224	07			224	11
		168	10			336	07			280	18
		224	12			448	21			308	19.5
		280	13.5			471	Broke.			322	33
		336	16	56. C.	20.3	448	25			336	24
		392	17			495	Broke.			342	Broke.
		410	Broke.	58. C.	23.7	224	49	85. L.	24.5	112	11.5
37. L.	22.	112	23			336	54			224	15
		162	43			392	50			336	33
		171	Broke.			448	44			392	38

[TABLE XCII. continued] *time of taking the elasticity. The direction of the slitting is indicated by the letters in the left hand column.*

No. of the bar and direction of the slit.	Length under trial.	Weight in the scale.	Elastic. observed correct. for the machine.
		420	36′
		448	24
		462	Broke.
85. L.	22.1	224	15
		336	23
		392	24
		462	28
		481	Broke.
87. L.	24.5	224	21
		336	16
		392	25
		441	25
		464	Broke.
75. L.	24.6	257	8
		262	Broke.
75. L.	21.4	168	10
		267	Broke.
78. L.	24.4	112	14.5
		224	17.5
		280	21
		280	Broke.
78. L.	Unc.	224	54
		293	Broke.
83. C.	24.	224	34
		273	Broke.
84. C.	23.8	168	50
		224	52
		275	54
		289	Broke.
84. C.	9.	224	33
		317	24
		319	Broke.
84. C.	15.2	280	53
		294	Broke.
91. C.	24.	112	50.5
		224	76
		280	60
		347	34
		364	20
		392	Broke.
94. L.	24.07	224	37
		280	45
		336	38
		392	36
		448	25
		483	25
		511	Broke.
95. C.	24.1	224	34
		336	26
		382	Broke.
99. C.	24.3	224	20
		336	36
		378	42
		378	Broke.

No. of the bar and direction of the slit.	Length under trial.	Weight in the scale.	Elastic. observed correct. for the machine.
101. L.	25.1	224	35′
		336	41
		403	Broke.
103. C.	23.8	224	38
		280	34
		308	43.5
		321	Broke.
103. C.	9.6	168	7
		361	Broke.
105. L.	24.2	224	63
		294	64
		320	63
		322	Broke.
130. C.	16.6	56	8
		112	8.5
		168	9
		224	11
		280	13.5
		336	12
		436	16
		466	12
		485	16
		506	24
		529	Broke.
137. Diagonal.	4.	490	44
		498	Broke.
142. L.	30.4	112	8.5
		224	14
		280	15
		336	27
		364	26.5
		380	32
		398	31.5
		415	Broke.
143. L.	30.6	224	30
		280	33
		336	48
		370	53
		392	52
		435	44
		440	47
		440	Broke.
143. L.	29.3	464	41
		478	Broke.
154. D.	30.4	224	30
		336	30
		392	38
		420	42
		427	Broke.
154. D.	23.08	392	21
		438	Broke.
157. D.	30.35	224	27
		336	50
		392	50

No. of the bar and direction of the slit.	Length under trial.	Weight in the scale.	Elastic. observed correct. for the machine.
		420	51′
		438	49
		448	45
		462	46.5
		468	Broke.
174. D.	30.2	219	45.5
		227	50.5
		235	Broke.
174. D.	27.7	231	65
		235	Broke.
174. D.	23.9	231	41
		245	44
		246	Broke.
174. D.	22.1	245	39
		246	Broke.
148. C.	unc.	212	29
		336	33
		392	42
		448	45
		463	Broke.
148. C.	20.6	463	37
		476	Broke.
151. C.	30.5	224	30
		336	33
		448	40
		476	Broke.
151. C.	29.8	476	36
		489	Broke.
167. C.	30.4	224	38
		266	36
		284	42
		292	Broke.
167. C.	19.33	306	29
		307	Broke.
160. L.	30.2	224	82
		245	Broke.
160. L.	22.25	252	64
		257	Broke.
162. L.	30.2	168	60
		224	65
		252	58
		256	Broke.
162. L.	27.6	262	72
		262	Broke.
181. Steel bar.		112	20.5
		224	30
		336	28
		385	36.5
		406	40.5
		415	39.5
		422	36.5
		429	37.5
		441	Broke.

TABLE XCIII.

Comparative view exhibiting the areas of section at the points of fracture in 151 *experiments on* 67 *different specimens of iron, embracing*

No. of the comparison.	Number of the specimen referred to.	No. of experiments on the respective specimens.	Area, after fracture, of strips cut lengthwise, compared with their original area as unity.	Area of section of fracture of specimens cut transversely, their original area being .1.	Mean area of length strips in each kind of iron.	Mean area of cross strips in each kind of iron.
1	2	2	.887			
2	4	2	.829			
3	6	2		.904		
4	8	1		.895	.858	.899
5	9	1	.876			
6	11	2	.771			
7	21	2	.909			
8	23	3	.876			
9	13	2		.860		
10	15	1		.867		
11	18	1		.964	.858	.897
12	25	6	.824			
13	27	1	.936			
14	35	1	.909			
15	37	1	.949			
16	32	1		.840		
17	39	1		.934		
18	41	1		.927	.904	.900
19	42	3	.923			
20	43	1	.924			
21	44	2	.914			
22	56	2		.920		
23	58	4		.883	.920	.901
24	46	2	.790			
25	48	2	.761			
26	51	2		.838		
27	53	2		.865	.775	.851
28	59	1	.890			
29	61	1	.891			
30	64	1		.967		
31	65	1		.940	.890	.953
32	68	2	.833			
33	70	1	.858			

Number of the comparison.	Number of the specimen.	Number of experiments on the respective specimens.	Area after fracture of strips cut lengthwise, compared with their original area as unity.	Area after fracture of specimens cut transversely.	Area after fracture of specimens cut diagonally.
34	71	4		.781	
35	73	1		.830	
36	85	3	.889		
37	87	2	.800		
38	75	1	.869		
39	78	1	.840		
40	81	1		.978	
41	83	3		.901	
42	84	3		.859	
43	94	4	.760		
44	95	5		.872	
45	99	1		.947	
46	103	2		.810	
47	107	3		.816	
48	101	2	.849		
49	105	1	.895		
50	125	2	.502		
51	130	1		.766	
52	133	5		.587	
53	135	5			.512
54	137	3			.544
55	142	1	.941		
56	143	3	.780		
57	160	5	.772		
58	162	2	.735		
59	164	5	.457		
60	148	2		.885	
61	151	5		.847	
62	167	2		.729	
63	169	6		.835	
64	154	3			.877
65	157	1			.842
66	171	1			.412
67	174	4			.805

TABLE XCIII.

11 kinds of metal, distinguishing those specimens which were cut lengthwise from those which were cut crosswise and diagonally from the sheet.

Mean area of longitudinal specimens.	Mean area of transverse specimens.	Mean area of diagonal specimens.	REMARKS.
·845	.805		From this table it appears that the areas of fracture in strips cut across the direction of the rolling, are greater than in those cut longitudinally. The difference in this respect on the 12 different kinds, averages 6 per cent. of the area of the fractures in the longitudinal strips,—a difference corresponding very nearly with the difference in *strength* of longitudinal and transverse strips as contained in Tables XCV. and XCVI. It also appears that of the 12 different sorts of iron compared, 8 exhibit a diminution of area in the *length* strips, greater than in those cut across the direction of the rolling, and 4 show a small balance in the opposite direction. The mean difference of the 8 sets first mentioned, is .861—.778=.083 of the original area, or .107 of .778, the remaining area in the case of the length strips. The mean of all the 67 comparisons in all directions exhibits the diminution of area from 1.000 to .835, or a "constriction" of .165=1-6 the original size, and of course a correspondent increase of length at the parts in the immediate vicinity of the fractures.
.849	.912		
.760	.872		
.872	.857		
.502	.679	.523	
.737	.824	.859	

Diminution of area at the moment of fracture.

With a view to determine within certain limits the extensibility of iron when subjected to strain, and to compare the same in specimens cut across the sheet with that of longitudinal strips, a considerable number of measurements were taken at the sections of fracture after the experiment, and from these the above table of results is exhibited, indicating the mean result of the trials on each bar and the ratio of the remaining area to the original area taken as unity.

In taking these measurements some little uncertainty is to be admitted, owing to the fracture taking occasionally a diagonal direction, but as the two fragments afforded the means of obtaining corrections, the error from this cause cannot have, at most, exceeded a few thousandths of an inch.

By referring to the table of permanent elongations as taken on the whole bar, (Table XCIV.), it will be seen that the greatest extension observed on an entire bar, previous to the first fracture, was 3 inches in 24 or $\frac{1}{8}$ of the total length. This was on a bar reduced to a uniform size. But as no bar of iron, of any considerable length, is of uniform strength throughout, we are not to expect in any case an extension in length *of the whole bar* equal to the diminution of area at the point of fracture.

One remark worthy of particular attention, in connection with our subject, is, that at elevated temperatures, before the diminution of strength has begun to be felt, the diminution of area or *constriction* of iron is often much less, than when the trial is made on the cold metal. This is particularly exemplified in bar No. 164, in which two experiments at 577°, gave a tenacity 14 per cent. greater than five others, made at from 75° to 80°, while the constriction was less in the hot trials than in the cold, in the proportion of .338 to .447, or about *one-third*. In this and similar cases the fractures at high temperatures were observed to take place suddenly, and the surfaces of fracture to present appearances altogether different from those found in cases where the same bar was broken cold. This peculiarity consisted in a smooth section, directly across the breadth of the filed portion in which they took place, but uniformly inclined to the flat face of the bar, in an angle of about 45 degrees, and presenting therefore a bevel, like the cutting edge of a common mortising chisel.

In a few instances, particularly in experiments on bars as they came from the shears, the fracture was compound, the strengths at two neighboring sections being so exactly equal as to separate simultaneously, at the distance of half an inch or an inch from each other.

Bars 228 and 230, the former of which was cut crosswise, and the latter lengthwise of the sheet, and both broken up at ordinary temperatures, indicated a marked difference in the nature of the surfaces of fracture. The former presents, in nearly all instances, irregular and jagged surfaces inclining to compound fracture, or displays rough sections perpendicular both to the edges and faces of the bar. The latter is oblique and fibrous.

The amount of constriction in strips cut across the direction of rolling is, on an average, about 6 per cent. less than in those cut longitudinally.

A careful comparison of the breadths and thicknesses before and after fracture would show that the diminution in thickness follows a more rapid rate than that in breadth, whether the iron be hammered or rolled, and whether in the latter case, it be cut lengthwise or crosswise of the sheet.

The amount of constriction observed, viz: $16\frac{1}{2}$ per cent., is rather less

than that obtained by M. Martin,* who operated chiefly on rolled bars or bolts of considerable magnitude, and found on an average of 35 comparisons $18\frac{6}{10}$ per cent. of elongation.

The above table will show that the difference in different kinds of metal in respect to the diminution of *area* of fracture is very marked, sometimes exceeding 54 per cent. of the whole original area; while at others it scarcely exceeds 5 per cent.

The difference in the extensibility of iron in the longitudinal and the transverse directions of the sheet is liable to manifest itself in practice, when a portion of a boiler becomes locally so overheated as to bulge out in a particular spot. It will then be seen that an elongated protuberance is exhibited, having the greater axis in the direction across the sheet, and the less lying in the course of the rolling.

The piece taken from an old boiler which had been burst in consequence of the gradual overheating of a portion over the fire where sediment had collected, and which will be referred to in another part of this report, exemplifies the kind of action above described. The extent of the swelling in the direction of the length of the sheet was $10\frac{1}{2}$ inches, which, measuring over the summit of the bulge, had become $12\frac{1}{4}$ inches; or the increase of distance over the surface of the metal was .167 of the original extent. In the transverse direction of the rolling, the original length of the swollen part was $20\frac{1}{2}$ inches, and the line applied over the summit measured 23 inches, or the increase in this direction was .122 of the original length. Hence the extensions of this specimen of iron in the two directions are to each other as 167 to 122.

Some idea may be formed of the extent of constriction in *breadth*, both of iron and copper bars under various temperatures, by inspecting Plate II. *m* and *m′* are two portions of bar No. 164, Table XLVIII., which was prepared by filing notches on its sides. The portion *m*, of which the breadth before trial was .747 inch in the deepest part of the filed section and .132 inch thick, was broken at a temperature of 576°. Strength, 66336 pounds per square inch. The breadth after fracture was .674 inch, and the thickness .102. The surface clean, smooth and bevelled in an angle of about 45°. The diminution of area is consequently .098604—.068781 = .029823 square inch. *m′* represents a portion broken in experiment 15 of the same table, at a temperature of 87.5°, giving a strength of 56503 pounds per square inch, and a section of fracture measuring .601 in breadth and .07 in thickness;—whereas the original breadth had been .731 and thickness .138; so that the constriction was here .100878—.042070=.058808 square inch,—almost exactly double as much as when broken at 576°. Experiment 17 on the same bar affords another illustration of the effect of a moderately elevated temperature in preventing constriction.

The original breadth of the bar in which these notches were filed was 1.117 inch. Hence the notches in *m* were each $\frac{1.117-.747}{2} = .185$ inch deep, and those in *m′* each about .193 inch, in both cases quite sufficient to preclude the supposition of any weakening effect of the shears, within the part left after filing.

n and *n′* are portions of the bar of iron, No. 224 C, an account of which is given in Table LXXII. The breadth before trial of this bar, which was reduced

* See Annales des Mines, 3d series, Vol. V. 1st part.

to uniform size by filing, is indicated by the dotted lines outside of the plain ones, while the inside dotted lines mark the breadths after fracture. Both portions were broken at low temperatures. *n′* in experiment 5 of that table, at a temperature of 80°, exhibited a strength of 62472 pounds per square inch, a breadth of section=.572 inch, and a thickness of .159, consequently giving an area of section after fracture of .090948 square inch, whereas the area before trial was .182945, and the constriction .091967, a trifle more than 50 per cent. of the original section. The fracture on the portion *n* was made at the 8th experiment of the same table when the temperature was 71°, and within one inch of the point broken in the trial just referred to. But previously to this fracture, the specimen had been submitted without access of air to a bright welding heat, so as perfectly to anneal the iron without oxidizing it. The strength was then found to be only 36052 pounds per square inch, reckoned on the original section at that part of the bar, the breadth being .457 inch, the thickness .118, and the area .053926; while the original breadth had been .757, original thickness, .24125, and area .182626, which had been reduced before the annealing to .150664. Hence the constriction after annealing was .182626—.053926=.128700, or 70.4 per cent. of the original cross section of the bar.

o and *o′* represent specimens of copper bar, No. 7 table XXII., to which we have already referred in speaking of the extensibility of that metal.

Forces producing permanent elongations of iron.

In connexion with the subjects of tenacity and elasticity, it has generally been deemed important to pay some attention to the relation between the forces which will break, and those which will elongate the specimens to a sensible degree, rendering them incapable of returning to their original dimensions. The committee have not been unmindful of this subject, and the following table will exhibit the most important of these observations, which have, during the course of our experiments, been made to bear directly on this point. An inspection will show that the first permanent elongation may take place under forces varying according to the character of the materials. Those kinds which possess the greatest extensibility begin in general earliest to manifest this property, in yielding *permanently* to low degrees of force. This remark is exemplified by a comparison between Nos. 226 and 219 A., the latter of which showed an extensibility before fracture of 2.5 inches in 24, or about $\frac{2}{19}$ of its whole length, and began to extend with $41\frac{2}{3}$ per cent. of the breaking weight, while the former was extended $\frac{1}{16}$ of its length, or $1\frac{1}{2}$ inch in 24, and required 76 per cent. of the breaking weight to cause the first elongation. The *extremes* lie between .416 and .872 of the ultimate strength; and the mean of 13 comparisons is .641, conforming nearly with the results obtained by former experimenters.

The eighth and ninth columns of the following table show the total elongation at the moment of fracture. This must necessarily be different in different bars, as well on account of the diversity in their constitution, as of the unequal degrees of *uniformity* in size and structure in different parts of the same bar.

TABLE XCIV.

Comparative table exhibiting the amount and relations of the weights required to produce the first permanent elongation in different bars of iron, and the weights required for the first fracture of each bar, also the amount of permanent elongation of the specimen, and the ratio which that elongation bears to the entire length before trial.

No. of the Comparison.	Mark of the bar affording the comparison.	Original length of the part measured.	Strength in lbs. per square inch, exhibited by the first fracture.	No. of pounds in the scale at the first frac.	Wt. in the scale at 1st permanent elongation.	Ratio of the *elongating* to the *breaking weight.*	Elongation in inches, at the time of fracture.	Pt. by which the original l'gth was increased.	REMARKS.
1	49	20.3	57565	316	245	.775	1.42	$\frac{1}{14}$	When strained with 273 lbs. and then relieved, the recoil of the part within the marks originally 20.3 in. apart, was .05 of an inch; with 301 lbs. in the scale it was .06, and with 306 lbs. it was .04. The mean of these 3 trials of the recoil, shows that it amounted to $\frac{1}{406}$ of the original length.
2	149	24.	52778	334	224	.670			
3	150	24.	59397	346	196	.566	1.5	$\frac{1}{16}$	
4	191	15.	47991	326	210	.644	1.42	$\frac{1}{11}$	
5	219 A.	24.	52257	267	112	.416	2.5	$\frac{1}{9.6}$	
6	220 B.	24.	58642	336	184	.547	3. +	$\frac{1}{8}$	Under 289 lbs. the 24 inches had become 27, and the bar had extended very uniformly.
7	223 A.	24.	43766	269	168	.622	1. +	$\frac{1}{24}$	
8	223 B.	22.	41555	262			2.55	$\frac{1}{8.6}$	The first permanent elongation of this bar was not observed, but under a weight of 245 lbs. in the scale the elongation was .7 inch.
9	226	24.	49053	315	240	.761	1.5	$\frac{1}{16}$	
10	228	24.	40643	266	232	.872			Under a weight of 238 lbs. in the scale, the elongation in 24 inches was .146 inch; but when relieved the recoil was .046, showing the permanent elongation to be .1 inch, and the ratio of the recoil to the total length $\frac{1}{521}$.
11	229	12.	46473	301	210	.697			
12	230	26.	49368	330	196	.594	2.36	$\frac{1}{11}$	
13	231	22.	68513	465	308	.662			
14	232	24.	57039	376	196	.508			
			Mean of 13			.641			
			Maximum			.872			
			Minimum			.416			

It is not only desirable to mark the force which will produce the first permanent elongation of iron, but also to ascertain the successive elongations under different weights, since in the case of the steam-boiler it may be necessary to know what degrees of distortion in its form would result from the various forces which might be applied to it. It is true that in producing these successive elongations *time* may enter as an element into the result; but the experiments of the committee on this subject, were generally conducted with such deliberation as to preclude the supposition that a longer continuance would have materially altered the effects observed. In determining this question, recourse was had to two methods; first, that of direct measurement of the lengths after certain elongating forces had been applied, and secondly, that of gauging the cross sections at numerous equi-distant points along the bar, the results of which showed the irregularity of extension as well as its actual amount in the vicinity of each section so gauged.

Table XLVIII. affords an example of the latter kind of trials, in which the bar was gauged each time, after eight different experiments.

Tables XXXVIII., XXXIX., XLII., LXXXII., LXXXIII., LXXXIV. and LXXXVII., will also be found to contain accounts of similar measurements of cross sections.

Experiments and observations on the progressive extensions *in length* of bars of iron, will be found in Tables XXXVII., XXXVIII., LXV., LXXXII. and LXXXIV.

Strength of iron in different directions of the rolled sheet.

In obtaining specimens for these experiments, care was generally taken to have them cut in different directions of the rolling, longitudinally and transversely, and in some cases *diagonally*, to that direction. The tables will be found to indicate the direction of slitting in each case, and the comparison contained in Tables XCV. and XCVI. is given to show what information the inquiry has elicited.

The comparison is made principally on the *minimum* strength of each bar, being that which can alone be relied on in practice; for if the strength of the weakest point in a boiler be overcome, it is obviously unimportant to know that other parts had a greater strength. In one case, however, two bars, one cut across the direction of rolling and the other longitudinally, were, after being reduced to uniform size, broken up cold, with a view to this question. The result shewed that the length-strip was $7\frac{1}{10}$ per cent. stronger than the one cut crosswise, considering the tenacity of the latter equal to 100. Of the other sets, embracing about 40 strips cut in each direction, it appears that some kinds of boiler iron manifest much greater inequality in the two directions than others. It is in certain cases not much over one per cent., and in others exceeds twenty, and as a mean of the whole series it may be stated to amount to six per cent. of the strength of the cross-cut bars. The number of trials on those cut diagonally is not perhaps sufficiently great to warrant a general deduction, but so far as they go, they certainly indicate that the strength in this direction is less than in either of the others.

Had we compared the mean instead of the least strength of bars as given in the table, the result would not have differed materially in regard to the relative strength in the respective directions.

For this purpose the boiler-iron manufactured by Messrs. E. H. & P. Ellicott, which was tried in all three of the directions of the sheet, and by all the three modes of preparation of specimens, will be found to give the following results,—viz, 1. When tried at *original sections*, seven experiments on length-sheet specimens gave a mean strength of 55285 lbs. per square inch, the lowest being 44399, and the highest 59307. Fourteen experiments on cross-sheet specimens gave a mean of 53896 lbs., the lowest result being 50212, the highest 58839; and six experiments on strips cut diagonally from the sheet, exhibited a strength of 53850 lbs., of which the lowest was 51134, and the highest 58773.

2. When tried by filing notches on the edges of the strips to remove all weakening effect of the shears, the *length-sheet* bars gave, at fourteen fractures, a mean strength of 63946, varying between 56346 and 78000 lbs. per square inch. The cross-sheet specimens tried after this mode of preparation, exhibited, at three trials, a mean strength of 60236 lbs., varying between 55222 and 65143; and the *diagonal* strips, at four trials, gave a mean result of 53925, the greatest difference being between 51428 and 56632.

3. Of strips reduced to uniform size by filing, four comparable experiments on those cut lengthwise of the sheet, gave a mean strength of 63947, of which the highest was 67378 and the lowest 60594.

Cross-sheet specimens tried after the same preparation, exhibited, at thirty-three fractures, a mean of 50176, of which the highest was 65785 and the lowest 52778. No bar cut diagonally was reduced to uniform size.

From the foregoing statements it appears that by filing in notches and filing to uniformity, we obtained results 63946 and 63947 for the strength of strips cut lengthwise, differing from each other but a single pound to the square inch, and that by these two modes of preparation the cross-sheet specimens gave respectively 60236 and 60176, differing by only 60 lbs. to the square inch. This seems to prove that by both methods of preparing the specimens the accidental weakening effect of slitting had been removed by separating all that portion of the metal on which it had been exerted. Hence we may infer that the differences between length-sheet and cross-sheet specimens are really and truly ascribable to a difference of texture in the two directions, which will be seen to amount, in the case of filing in notches, to 6.15 per cent., and in that of filing to uniformity, to 6.26 per cent. of the strength of the cross-sheet specimens.

The single exception to the law that the greater strength is given in the longitudinal direction of the rolling, will be found explained in the remark appended to table XCV.

TABLE XCV.

Comparative view of the strength of specimens of ten different sorts of boiler and one of bar iron, in the longitudinal, transverse, and diagonal direction of the rolling, as deduced from the least

No. of the specimen referred to.	Strength in the longitudinal direction.	Strength in the transverse direction.	Specific gravity.
2	58977		7.7169
3	53828		7.7169
4	4714		7.7169
6		52280	7.7169
8		50103	7.7169
Mn.	53324	51191	
9	57952		7.7874
10	64133		7.7874
11	42000		7.7874
13		50488	7.7874
14		52542	7.7874
15		50166	7.7874
16		50039	7.7874
17		44249	7.7700
18		50218	7.7700
19		49125	7.7764
21	38618		7.7700
22	47491		7.7700
23	42798		7.7700
Mn.	48832	49546	
25	43921		7.7640
27	55636		7.7640
30		44703	7.7640
32		52197	7.7640
35	43237		7.7954
37	46155		7.7954
39		40595	7.7954
41		37713	7.7954
Mn.	47237	43802	
42	51653	Puddled.	7.6820
43	44102	do.	7.6820
44	53836	do.	7.6820
46	59262	H'd pla.	7.6785
48	59418	do.	7.6785
49	57565	do.	7.6785
51	H'd pl	59656	7.7567

No. of the specimen referred to.	Strength in the longitudinal direction.	Strength in the transverse direction.	Specific gravity.
53	H'd pla.	56062	7.7567
56	Puddled.	57926	7.6511
58	do.	50570	7.6511
59	48308	Puddled.	7.6013
60	58684	do.	7.6013
61	52869	do.	7.6013
62	57612	do.	7.6013
64	Puddled.	45392	7.6511
65	do.	51255	7.6511
68	57929	H'd pla.	7.7900
70	47638	do.	7.7900
71	H'd pla.	54634	7.7900
73	do.	52657	7.7900
74	do.	49351	7.7910
Mn.	54074	53049	
75	60408		7.7580
78	41734		7.7580
81		42903	7.7580
83		42162	7.7580
84		42696	7.7580
85	48694		7.7580
86	58969		7.7580
87	50249		7.7580
88	49508		7.7922
90		45060	7.7580
91		42365	7.7580
Mn.	51760	43037	
94		53811	
95		45471	
99		49548	
101	49258		
103		41319	
105		44591	
107		55461	
Mn.	49258	48366	

No. of the specimen referred to.	Strength in the longitudinal direction.
125	57182
130	Tilted.
133	do.
135	do.
137	do.
Mn.	57182
142	44399
143	53135
146	60594
148	
149	
150	
151	
152	
154	
157	
160	
162	
164	56346
167	56682
169	54361
171	
174	
Mn.	54253
200	
201	
206	44149
207	48120
208	52175
Mn.	48148
226	
227	
228	
229	
230	49368
Mn.	49368

TABLE XCV.

strength of each specimen, and the average minimum of each sort of iron, in each direction in which it was tried, together with the specific gravity of the several bars.

Strength in the transverse direction.	Strength in the diagonal direction.	Specific gravity.	REMARKS.
Tilted.			
57789			
53176			
	47738		
	50358		
55882	49048		
		7.7390	The only set of these experiments in which the bars cut crosswise of the sheet appear to be stronger than those cut lengthwise, is that from 9 to 23,—of which 3 of the length strips were from the same specimen,—a specimen in which a large flaky portion was developed by the trial. This set is therefore not to be taken into the account in computing the relative strength of the two classes of bars. The specimens from 42 to 74, were partly puddled iron, and partly Juniata blooms, hammered and rolled into plate. The length and the cross-sheet specimens of these two kinds must be compared separately as shown in the table (XCVI.) of general results. All the experiments on No. 228 (cross,) and 230 (length,) were made at ordinary temperatures with a view to this comparison.
52468			
52228		7.7774	
56869		7.7774	
53811			
56073		7.7774	
	51134		
	52102		
53862			
50212			
	55612		
	51425		
53646	52568		
40163			
46970			
43566			
49053		7.7428	
53699		7.6675	
40643		7.6675	
46473		7.7428	
		7.6675	
47467			

TABLE XCVI.

General results of the several comparisons between bars cut in the different directions.

Sets of specimens compared.	No. of experiments on longitudinal bars.	Strength of specimens cut lengthwise.	No. of experiments on transverse bars.	Strength of specimens cut crosswise.	No. of experiments on diagonal bars.	Strength of bars cut diagonally.	Excess of longitudinal, over transverse specimens.	Excess compared with the whole strength of the cross cut bars as unity.
2— 8	3	53324	2	51191			2133	.0416
25— 41	4	47237	4	43802			3435	.0784
75— 91	6	51760	5	43037			8723	.2026
94—107	1	49258	6	48366			892	.0184
125—137	1	57182	2	55482	2	49048	1700	.0306
142—174	6	54253	7	53646	4	52568	607	.0113
200—208	3	48148	2	43566			4582	.1051
226—230	1	49368	4	47467			1901	.0421
Ham'd plate.	5	56366	5	54872			1894	.0347
Puddled iron.	7	52437	4	51411			1026	.0200
Mean of	37	51933	41	49247	6	50808	2689	.0585
Mn. of ex. on 228—230	13	54022	13	50433			3589	.0711

From the above comparison of nearly eighty specimens, from ten different sorts of iron, it appears that the average minimum strength of iron in the direction in which it is rolled, is very nearly 6 per cent. greater than that in the transverse direction.

Specific gravity of Boiler-Iron.

Table XCV. contains in addition to a view of the relative tenacities of strips cut lengthwise and crosswise of the boiler plate, a column exhibiting the specific gravities of the several kinds of iron there compared. In most cases, these were obtained by cutting from the same sheet which furnished the strips, and in a contiguous part, a small sample, expressly intended for a trial of its density. Several bars will consequently be found to have the same specific gravity assigned to them. But we have still no less than nineteen different experiments from which to deduce the general result. From these it appears that the highest density was 7.7922, the lowest 7.6013, and the mean 7.7344; also, that the difference .1909, between the maximum and the minimum is $\frac{1}{40.5}$ part of the mean density, which may accordingly be taken as the limit of variations in this particular.

Seventeen different trials of specific gravity on *bar* iron gave a mean of 7.7254, and the greatest difference between any two results was 7.8319—7.4587=.3832, or $\frac{1}{20.1}$ of the mean density.

Effect of repeated Piling on the tenacity of Plate-Iron.

The effect of repetitions of the process of piling and welding, whether of puddled iron or blooms, is exhibited in table XCVII., in which are contained the results of trials on three specimens of iron, furnished by an establishment in Centre County, Pennsylvania, a region known to afford an ore of superior quality, and which has long supplied wrought iron, inferior to few other kinds of the article known in the American market.

TABLE XCVII.

Experiments on bars No. 242, 243 and 244. Manufactured by Messrs. Valentine & Thomas, near Bellefonte, Centre County, Pa., from metal obtained from pipe ore, *found 15 miles north of that place. No. 242 from "refinery bloom", extended into bars three inches wide by one inch thick, piled four high and twice welded. No. 243 also from "refinery bloom," twice welded. No. 244 manufactured from puddled iron, rolled at the first operation into 3½ by 1 inch, then cut up and piled 4 tiers high, welded again and extended into a billet, then a second welding and rolling into the shape in which it was received.*

No. of the bar.	No. of the experiment.	DATE.	Breadth before trial.	Thickness before trial.	Area of section before trial.	Breaking weight in the scale.	Breaking weight × leverage.	Friction.	Effective strain.	Strength in pounds per square inch.	REMARKS.
242	1	1835. Nov.	.753	.222	.167166	342	10260	513	9747	58308	All the bars had been reduced when received to such a state of uniformity in size as allowed them to be considered as equal throughout and equal to each other. The experiments on 242 prove that the mean str'gth is 59247 lbs., and the irregularity between experiments 1 and 3 is 2047, or a little more than 1-29 of the mean strength.
"	2	"	do.	do.	do.	349	10470	523	9947	59505	
"	3	"	do.	do.	do.	354	10620	531	10089	60355	
"	4	"	do.	do.	do.	345	10350	517	9833	58820	
243	5	Nov.	.753	.222	.167166	340	10200	510	9690	57972	From experiments on this bar it appears that the mean strength was 58787 lbs., the difference between experiments 1 and 5 is 2718 or the irregularity amounts to 1-21.6 part of the mean strength.
"	6	"	do.	do.	do.	340	10200	510	9690	57972	
"	7	"	do.	do.	do.	343	10290	514	9676	58480	
"	8	"	do.	do.	do.	345	10350	517	9833	58820	
"	9	"	do.	do.	do.	356	10680	534	10146	60690	
244	10	Nov.	.753	.222	.167166	332	9960	498	9462	56600	From these experiments it is seen that the mean strength of the puddled bar was 57513 lbs.—the greatest difference, that between experiments 1 and 6, is 2390, or almost exactly 1-24 of the mean strength.
"	11	"	do.	do.	do.	335	10050	502	9548	57115	
"	12	"	do.	do.	do.	335	10050	502	9548	57115	
"	13	"	do.	do.	do.	336	10080	504	9576	57285	
"	14	"	do.	do.	do.	340	10200	510	9690	57972	
"	15	"	do.	do.	do.	346	10380	519	9861	58990	

Results.—1. The specimen which had been made from *refinery bloom* reduced to a bar 3 inches wide by 1 thick, piled 4 high and twice welded, proved the strongest. Not only did it exhibit the high mean result of 59247 pounds to the square inch, but the consistency and uniformity of the metal were such as to show between the highest and the lowest results a difference amounting to only 3.4 per cent. of that mean.

2. The specimen which had undergone two weldings, but had not been drawn into a bar and piled, was inferior to the preceding, giving a mean result of 58787; and the difference between the extremes exceeds 4.6 per cent. of that amount.

3. The specimen manufactured from puddled iron, rolled at the first operation into a bar $3\frac{1}{2}$ inches wide by 1 inch thick, cut and piled 4 tier high and then twice welded and rolled into bars little more than $\frac{2}{10}$ of an inch in thickness, was obviously designed by the manufacturers to correspond in all particulars with No. 1, except that the latter was from the bloomery, and the other (No. 3.) from the puddling furnace. The mean absolute strength of this specimen was decidedly less than that of either of the preceding, being only 57613 pounds, while the variation from uniformity was 4.1 per cent. of its mean strength.

Effects of Piling into the same Plate, Iron of different degrees of fineness.

It is believed to be a practice, not unknown among the manufacturers of boiler iron to combine into the same slab, and subsequently to roll into plate, iron of different qualities. In such cases the want of homogeneousness may manifest itself in a variety of ways. The different kinds may not be equally welded together throughout, and may consequently exhibit flaws at the surfaces of lamellation. They may be very unequally extensible under the same force, and while the outer ply of metal may, in turning a flanch, remain unbroken, the interior one may be greatly reduced in strength. They may be of different specific gravities and mislead the purchaser, who looks only upon the exterior face of the plate, and judges of its value by the good appearance of the latter, and the weight of the whole per square foot under a given thickness.

By a reference to table XXXIII., in experiments on bars 39 and 41, it will be seen that a considerable defect, of the nature above alluded to, was exhibited, and the low results given in those cases, (40600 and 37700 lbs. per square inch) afford conclusive evidence of the bad quality of boiler plate in which such defects of welding between the laminæ exist.

In table XLIX., experiment 16, another example of the same kind occurs, in which a decided difference of appearance in the fracture showed itself between the interior and exterior folds of the metal.

Effects of the Rivets on the Total Strength of Boilers.

In whatever manner the parts of a steam boiler are united, the rivets which form the junctures being substituted for portions of the metal cut away to receive them, are of necessity so much deduction from the strength of the entire sheet, and unless we can suppose that the strain brought upon the rivet by the manner of setting it, when hot, and in that state making so close a bearing as, when cold, to contract and create a pressure that shall furnish an adhesion by friction between the overlapping surfaces, equal in amount to the strength taken away by the line of rivet holes, we cannot in

computing the absolute strength of any steam boiler, safely rely on more than the portion of metal which remains in the intervals between the holes. That the requisite amount of friction could not, under the circumstances which practice assigns to the case, be produced in the manner supposed, is easily demonstrable, since, for that purpose, the friction on two square inches of surface, (the amount which on each side of the line of rivets could possibly be available for this purpose,) must be equal to the strength of the part cut away, which seldom falls short of $\frac{5}{8}$ of an inch. If we could suppose the rivet of this size so strained by hot working and shrinking as to exert $\frac{2}{3}$ of its entire strength or what would be just sufficient to produce in it a permanent elongation, then as its area of section would be .3068 of a square inch, admitting the iron of which it was made to be capable of bearing 55000 lbs. to the square inch, we should have an actual pressure of $55000 \times \frac{2}{3} \times .3068 = 11249$ pounds to be distributed over 4 square inches, giving for each of the two sheets 5624 pounds of pressure, the *friction* of which is to counteract the cutting away of $\frac{5}{16}$ of its substance.

If we suppose the plate to have the same strength per square inch as the rivet, and $\frac{1}{4}$ of an inch in thickness, two-thirds of the strength of the part cut away ($\frac{5}{8}$ of an inch wide,) would be 5726 pounds. From this it is evident that for a weakening of 5726 pounds, we have only the compensation of the *friction* produced by a pressure of 5624 pounds. That fractures not only do take place along the lines of rivets when violent explosions occur, but that incipient fractures and permanent elongations are presented at the spaces between the rivet holes, is evinced by the appearance of the holes themselves elongated by strains and especially by overheating in the vicinity of the juncture. Examples of this are found in Table XCVIII.

In a piece of boiler iron which had been some years in use, and which from overheating, in consequence of the collecting of a quantity of sediment in the part immediately above the fire, had become locally swelled into a protuberance reaching nearly the breadth of a sheet and from nine to ten inches in the direction of the curve, the rivet holes on both sides of the sheet, opposite to the protuberance, were found to be elongated as in the following table. All those on the side nearest to the summit of the protuberance, were found to have cracks running out in different directions, and in some cases, nearly traversing the entire space between the two adjacent rivets. (See the figure, page 238.)

Within half an inch of the first five rivets, and parallel with their line, a strip *a*, one inch wide, was cut from this piece of boiler, and tried at several filed sections. The report of these trials will be found in Table C. from which it will be seen that the portion nearest to the protuberance, and which had been reduced in thickness by the stretching, possessed much less strength *per square inch* than that which was still of the original thickness of the sheet. The surface of this bar, when the oxide had been removed, presented a distinctly spongy or *honey-comb* appearance, having many minute cells, which being developed by the shears were seen to be nearly filled up with oxide. The committee took an opportunity of making direct trial of the diminution of strength by rivetting. A bar of iron $\frac{9}{10}$ of an inch wide and .134 inch in thickness was rivetted together at a lap six inches long, by 12 rivets, each .205 inch in diameter, in two rows along the length of the bar, but alternating with each other in a zigzag course, the rivet near one edge being about one-third of an inch in advance, along the length, of the preceding one on the opposite edge.

TABLE XCVIII.

Effect of unequal strains on rivet holes.

No. of rivet holes.	Position of the rivet holes.	Length of the major axis of the rivet hole lying in the direction towards the swelled portion.	Length of the minor axis transverse to the swell, and in the line of the series of rivets.	REMARKS.
		Inch.	Inch.	Refer to fig., page 238.
1	At the part of the plate nearest to the swelling.	.750	.700	The centre of the rivets in this piece of boiler iron were 2 inches apart. Two cracks proceeded from this hole, one towards the interior of the sheet 4-10 inch long, the other towards the next rivet, 9–10 inch long.
2	Do.	.735	.650	An oblique crack proceeding gradually towards the interior but more rapidly to the next rivet, 9-10 inch long.
3	Do.	.740	.700	Crack proceeding towards the next rivet $\frac{3}{4}$ inch in length.
4	Do.	.705	.670	Two cracks proceeding in opposite directions, one 2-10 inch, the other 3-10 of an inch.
5	Do.	.750	.705	These cracks proceeding from the periphery of this hole, each from 3 to 4 tenths of an inch in length.
6	At the part of the plate most remote from swelling.	.725	.700	No cracks observable.
7	Do.	.715	.700	Do.
8	Do.	.675	.645	Do.
9	Do.	.690	.665	Do.
10	Do.	.665	.665	This hole appears to be the only one which retains its original size and shape.

The above described compound bar broke with an oblique section 1.05 inch long, passing through two rivet-holes.

The *strength* computed on the area of *cross* section was 52580 pounds, which reduced to the area of the actual oblique section is 45068 per sq. inch.

The same bar afterwards broken at a point six inches from the foregoing fracture, exhibited a strength of 66027 pounds. If we conceive the diameters of two rivets deducted from the cross section there remains but .49 of an inch in the breadth of the strap of iron which supported an effective strain of 6341 pounds. But the diagonal section of fracture had an area, after deducting the diameters of two rivet holes, of $.64 \times .134 = .08576$, whereas at the place of fracture, six inches distant, the area was .113529. The effective strain which broke the bar in this latter case was 7496 lbs. Applying this as a standard to the actual section of fracture at the rivets, we have the following calculations :—

1. For the weakening effect of cutting away the metal at the rivets; .113529 : .1407 : : 7496 : 9290=the effective strain which would have been borne by a section of this metal, 1.05 inch wide and .134 inch thick, had none been cut away to make room for the rivets. But the actual area left was

only .08576. Hence .113529 : 08576 : : 7496 : 5662 which ought to have been borne if no strengthening influence had been exerted by the rivets. The difference, or 9290—5662=3628, is the reduction of strength by cutting out the two cylindrical holes; but the actual effective strain was 6341. So that the weakening effect is in fact 9290—6341=2949.

2. The strengthening effect of the friction is 6341—5662=679.

Construction of Cylindrical Boilers and Flues.

In connection with the subject of rivetting it may be remarked, that unless a due regard to the form of the parts of a boiler be observed in constructing it, and a due attention to the rivet holes in the different pieces, the strains incidental to the boiler in its regular use, may be made more dangerous than that which would arise from the mere elastic energy of the steam alone. The usual practice in constructing cylindrical boilers and flues is to make the portions in the form of frusta of cones, the smaller end of one of which entering the larger end of the next, is rivetted in such a manner as to turn all the outer laps in the direction of the *fire end* of the boiler. It is evident that in such a construction the several plates which constitute a single ring of the boiler must have the lines of rivets along their *ends* placed in converging *right lines* and those along the sides or longest edges, in circular arcs of different radii. If in any case these lines are inconsistent with the positions of others to which they are required to conform, the holes must either be rimmed out, or the sheet unduly strained in attempting to force a conformity of positions.

In every case in which a just construction by the aid of previous calculation is obtained, the centres of the rivet holes are the points from which our calculations must commence.

It is obvious that the diameter of the cylindrical, or rather of the compound conical, shell, must constitute one element of the calculation, the breadth of the sheets a second, and the thickness of the metal a third. From these data may be found the radii of the curves in which are to be placed the rivets, and also the convergency of the two straight lines along the two ends of each sheet. The difference in the exterior diameters of the two ends of each frustum must at their respective rivet-lines be equal to twice the thickness of the metal. The larger arc for the rivet holes must manifestly be described by a longer radius than the smaller, and the difference of the two radii is the breadth of the sheet between the curves.

The larger radius will in every case be found *by adding to the mean exterior diameter of the boiler in inches, the thickness of the plate in the same denomination, multiplying the sum by the breadth of the plate, and dividing the product by twice the thickness of the plate.**

Effects of use and long exposure on the strength of boiler-iron.

This topic may be regarded as one of the most important which came under the notice of the committee. To treat it in all its bearings would demand far more of time and means that were at our disposal.

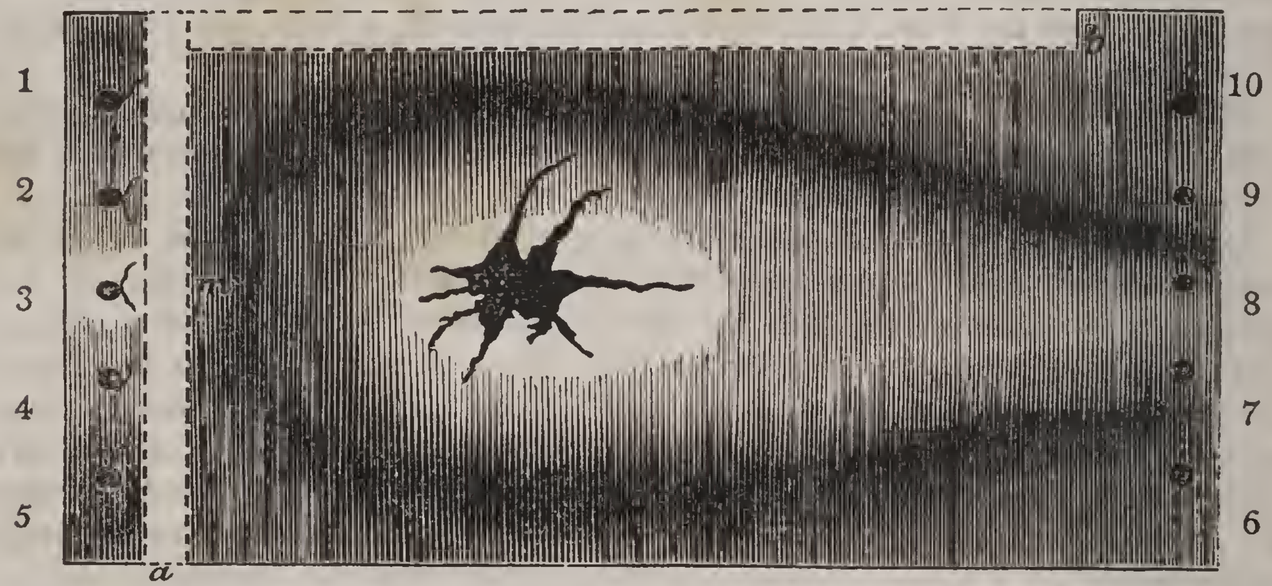
* Thus putting D=the exterior diameter of the boiler,
t=the thickness of the metal,
b=the breadth of the sheet between the two arcs of rivets,
A=the length of the greater arc which will reach round the larger end of the frustum,
a= " less Do.
R=the radius of the greater arc,
r= " less; so that $R-r=b$,
also $\pi=3.1416$.

Table C. contains the results of trials on four bars or strips cut from pieces of plate which had been long in use, and which were more or less visibly affected by the strain, or by the action of water and steam to which they had been subjected. They were cut lengthwise and crosswise respectively from the sheets out of which they were taken, one bar in each direction out of each sheet.

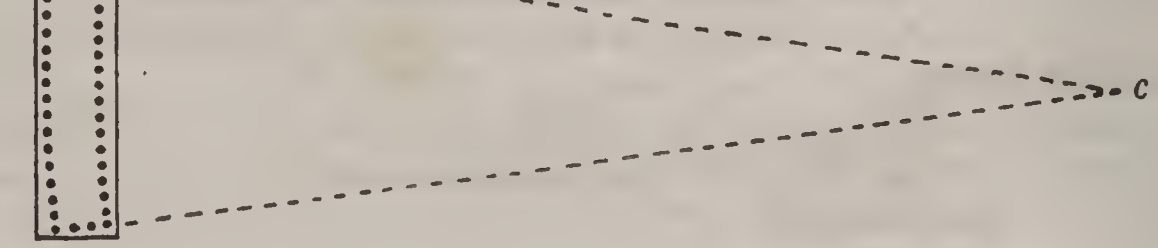
The two strips, Nos. 245 and 246, taken from a specimen of plate which had been burst, are represented in position by the dotted lines in the accompanying sketch. The length of the specimen is the original breadth of the sheet and lay as usual in the direction of the length of the boiler, 30 inches in diameter, from the bottom of which near the fire-end this piece was taken. Hence the shorter strip (*a*) is a length sheet strip, and the longer (*b*,) a cross sheet strip.

Agreeably to what has already been shown, the former possessed the greater strength, but the second experiment upon it made at the point *m*, where the swelling commenced, was found, as shown in the table, considerably weaker than the sections near the two ends of the strip.

The amount of the swelling on this specimen of iron may be seen by the two sketches, page 239, one of which is longitudinal and the other transversal, and the lengths of the ordinates, from lines at right angles to each other, and both passing over the centre of the swelled part, at *b* will be found in the



Then, since the arcs are similar, $\mathcal{A} : a :: R : r$ and $\mathcal{A}—a : \mathcal{A} :: R—r : R$. But $\mathcal{A}=\pi\ (D+t)$ and $a=\pi\ (D—t.)$ Hence $\mathcal{A}—a=\pi\ (D+t) — \pi\ (D—t) = 2\,\pi\, t$. Hence by the above proportion and putting b for $R—r$ we obtain $2\,\pi\, t : \pi\, (D+t) :: b : R$, from which results $R=\dfrac{b(D+t)}{2t}$, and $r=\dfrac{b(D+t)}{2t}—b$. As there must be the same number of rivet holes in each arc, a knowledge of the lengths of the respective arcs and of the number of rivets to be placed round the boiler, determines their distances from each other, on the two curves respectively. The accompanying figure represents the arrangement of the rivet-holes in a plate of metal adapted to constitute a part of a cylindrical boiler, with the centre *c*, and radii *cy* and *cx* of the two arcs of rivet-holes.



accompanying table. The ordinates on the inside or concave part of the plate, commence Fig. 1 from the centre of the rivet holes nearest to the place of rupture b. The points on the two axes were 1.075 inches apart.

TABLE XCIX.

No. of mark on the line lengthwise of specimen.	Ordinate or distance of the line from the bottom of the cavity in inches.	REMARKS.	No. of mark on the line transverse to the curvature of the piece.	Ordinate or distance from the co-ordinate to the inner surface of the swell.	REMARKS.
1	.150		1	.700	
2	.500		2	1.425	
3	.945		3	2.200	
4	1.430		4	2.720	
5	2.000		5	2.960	The rupture was opposite to these marks.
6	2.075		6	2.320	
7	2.350	The rupture was opposite to these marks and the distances could not be measured with the same precision as the rest.	7	1.745	
8	1.975		8	0.940	
9	1.870		9	0.390	
10	1.600		10	0.000	
11	1.360				
12	1.115				
13	0.940				
14	0.665				
15	0.520				
16	0.395				
17	0.350				
18	0.265				
19	0.145				
20	.080				

The original distance in the line ac, Fig. 1., was $22\frac{1}{2}$ inches. The length of the curve abc by actual measurement was found to be 24.6 inches. Hence the extension of the metal in this direction had been 2 1-10 inches in 22 5-10 or $\frac{1}{10.7}$ of the whole length.

Fig. 1.

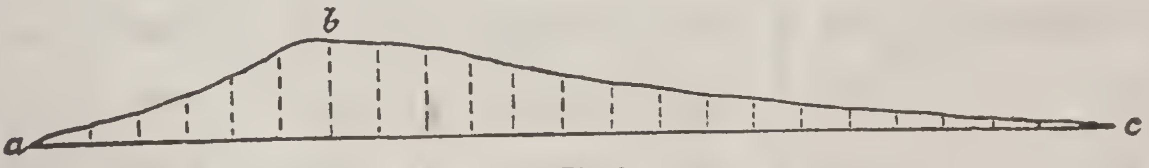
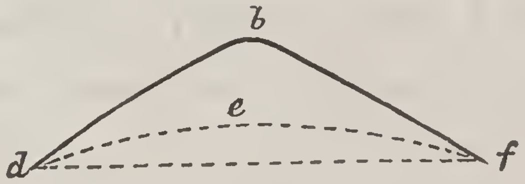


Fig. 2.



The length in the direction of the curve def, Fig. 2., was originally 10.6 inches. Actual measurement over the curve dbf, gave the length 12 inches, showing an elongation of fibres in this direction equal to 1.4 inches in 10.6 or $\frac{1}{7.5}$ of their whole original length. This greater extension of the fibres in the longitudinal direction of the sheet, accords with what has already been proved by direct trials on bars cut from new plates.

TABLE C.

Experiments on old boiler iron, Nos. 97, 98, 245 *and* 246. *The two former manufactured by Lukens, and the two latter uncertain, all having been some time in use, and visibly affected by the action of heat*

No. of the bar.	No. of the exp't.	DATE.	Breadth of the section of fracture before trial.	Thickness of the section of fracture before trial.	Area of the section before trial.	Temperature.	Breaking weight.	Breaking weight × leverage.	Friction.
97	1	1836. Feb. 13.	.785	.197	.154645	45°	273	8190	409
"	2	"	1.000	.215	.215000	45	349	10470	523
"	3	"	1.100	{ .100 .200 }	.165000	45	282	8460	423
"	4	Feb. 27.	.736	.217	.159712	41	285	8550	427
98	5	Feb. 13.	.720	.194	.139680	45	238	7140	357
"	6	Feb. 27.	.705	.214	.150870	41	275	8250	412
"	7	"	1.000	.182	.182000	41	338	10140	507
"	8	"	1.051	.220	.231220	41	373	11190	559
245	9	Mar. 21.	.661	.165	.109065	50	207	6210	310.5
"	10	"	.732	.141	.103212	50	170	5100	255
"	11	"	.731	.181	.132311	50	228	6840	342
246	12	Mar. 26.	.704	.182	.128128	51	206	6180	309
"	13	"	.721	.182	.131222	51	219	6570	328
"	14	"	.686	.182	.124852	51	212	6360	318
"	15	"	.693	.183	.126126	51	231	6930	346.5

TABLE C.

or corrosion. The two latter were from a specimen in which was a rupture in consequence of the collection of a sediment over the part exposed to the fire.

Effective strain.	Strength in lbs. per square inch.	REMARKS.
7781	50314	This strip was cut crosswise of the sheet,—filed section, edges and faces both filed.
9947	46265	Original section produced by the shears.
8037	48103	Fracture at a part deeply corroded. The thinnest place before trial was found but one-tenth of an inch thick.
8123	50860	The edges of this section of fracture were deeply filed, and the oxide was removed from the faces of the bars.
6783	48561	Filed on both edges and faces. Cut lengthwise.
7838	51952	Filed deeply on the edges. Oxide barely removed from the faces.
9633	52928	The edges barely straightened, much filed on the faces.
10631	45982	Edges barely straightened by filing—faces unfiled.
5989.5	54000	Deeply filed on the edges. Oxide removed from the faces. This strip cut lengthwise of the rolling.
4845	46942	This part of the bar had been over-heated, and stretched. Deeply filed as above.
6498	49111	Deeply filed, and oxide removed.
5871	45821	This strip cut crosswise from the ruptured specimen. (See figure on page 238.) Filed and scale removed.
6242	47568	Filed and cleared of oxide as above.
6042	48465	Do.
6583.5	52205	Do.

The two specimens, Nos. 97 and 98, Table C., were deeply corroded in certain parts, indicating the existence of local chemical actions arising probably from inequalities in either the purity, or the mechanical structure, of the sheet.

In both sets of the above trials on old boiler-plate it will be observed that though the mean strength is low, being under 50000 pounds per square inch, yet the principle is still preserved which assigns a greater tenacity in the longitudinal than in the transverse direction of the rolling. The difference, in this respect, between Nos. 245 and 246 is 50017—48515 or 3 per cent. of the strength of the transverse strip.

Between Nos. 97 and 98 the difference is somewhat less.

Effect of Annealing on the tenacity of Iron.

In a variety of cases the committee have endeavoured to extend the range of their experiments so as to embrace the condition of a steam-boiler which without being exploded has suffered from the exposure of its fire-surface when destitute of a due supply of water, to the action of heat above redness. In a few of the trials at elevated temperatures, this point was attained or surpassed, and the subsequent trials on parts near the places of fracture in such cases, gave evidence that the condition of the metal in regard to tenacity had been altered. In the case of bar No. 13, Table XXXI., it will be observed that annealing, which in that instance was produced by the folding over of the ends of the bar to obtain a more certain hold by the wedges, determined at once the place of fracture.

On specimens 199 B and 199 C, Table CII., which were wires manufactured at Phillipsburg from Juniata iron, were made several experiments to ascertain its mean tenacity, in the ordinary state of the article. On other pieces of the same wires the process of annealing at high temperatures was performed. The results show that the maximum effect of annealing on one of the sizes was a diminution of 27.5 per cent., and on the other 46 per cent. of the original strength.

In these instances the annealing was performed in a common smith's fire, without using any other precaution to defend the wire from oxidation than merely covering it with cinder.

This prevented, for the most part, any action of the air on the wire during the short time of its remaining in the fire. But to obviate altogether the objection that oxidation might have some share in producing the weakening effect, several specimens of iron were, after being carefully gauged, weighed and, having their specific gravities taken, rolled up in several folds of clean sheet iron; the ends of the folds turned over and hammered flat, to prevent access of air, and the whole then exposed for 15 or 20 minutes to the blast of a smith's fire, gradually raising it to a very high *welding heat*. In this state the package was withdrawn from the fire, often exhibiting one or two folds of the sheet iron cut through by the blast, but in no case extending to the enclosed specimens. When taken from the fire it was immediately buried in dead cinders, where it was allowed to remain until quite cold. The wrapping of sheet iron was then removed, and the specimens generally found with no visible change except a slight discolouration by black oxide of the metal, insufficient, however, to affect sensibly the weight of the specimen.

The five trials on Nos. 224 C and 254 D were among those which had been reduced or *constricted* by straining before the specimens were annealed.

TABLE CI.

Wrought iron annealed at different temperatures.

No. of the comparisons.	No. of the specimen on which the trial was made.	No. of the table containing the results on each specimen.	Strength at ordinary temperature before annealing.	Temperature at which the annealing took place.	Strength at the annealing temperature.	Strength after annealing and cooling.	Rate of diminution in strength by annealing.
1	152	LI.	57133	1037°	37764	55678	.025
2	214	LXII.	59219	1022	37410	46612	.213
3	227	LIV.	53774	1111	27604	52186	.029
4	226	LIII.	52040	1142	18672	44720	.140
5	227	LIV.	53774	1155	21967	45597	.152
6	229	LVI.	53185	1159	25620	46212	.131
7	227	LIV.	53774	1187	21919	45027	.162
8	226	LIII.	52040	1192	29703	43154	.170
9	226	LIII.	52040	1237	21298	44165	.151
10	226	LIII.	52040	1245	20703	38843	.253
11	224C.	LXXII.	48407	Bright welding heat.		36052	.255
12	224C.	LXXII.	48407	Do.		39333	.187
13	224D.	LXXIII.	48830	Do.		35889	.265
14	224D.	LXXIII.	48830	Do.		36706	.248
15	224C.	LXXII.	48407	Do.		38676	.201
16	19	XXXII.	52912	Do.		44191	.165
17	199B.	CII.	73880	Low welding heat.		53578	.275
18	199A.	LXIV.	76986	Bright welding heat.		50074	.349
19	199C.	CII.	89162	Low welding heat.		48144	.460

TABLE CII.

Experiments on two specimens of wire, Nos. 199 *B. and* 199 *C.* }
Manufactured at Phillipsburg, Pa., from Juniata iron. One specimen }

No. of the exp't.	Diameter of the wire.	Area of section of the wire before trial.	Temperature when tried.	Breaking weight in the scale.	Breaking weight × leverage.	Friction of the machine.	Effective strain.
	inch.	square inch.					
1	.190	.0283526	70°	73.	2190	109.5	2080.5
2	do.	do.	70	73.	2190	109.5	2080.5
3	do.	do.	70	74.5	2235	111.7	2123.3
4	do.	do.	70	74.	2220	111.	2109.
5	do.	do.	70	73.	2190	109.5	2080.5
6	do.	do.	76	49.5	1485	74.2	1410.8
7	do.	do.	76	54.5	1635	81.7	1553.3
8	do.	do.	76	62.	1860	93.	1767.
9	do.	do.	76	61.5	1845	92.2	1752.8
10	do.	do.	76	61.5	1845	92.2	1752.8
11	do.	do.	76	52.	1560	78.	1482.
12	do.	do.	76	53.5	1605	80.2	1524.8
13	do.	do.	76	52.5	1575	78.7	1496.3
14	do.	do.	76	54.	1620	81.	1539.
15	do.	do.	76	54.5	1635	81.7	1553.3
1	.156	.0191127	76	60.	1800	90.	1710.
2	do.	do.	76	60.	1800	90.	1710.
3	do.	do.	76	59.5	1785	89.7	1695.3
4	do.	do.	76	60.	1800	90.	1710.
5	do.	do.	76	59.5	1785	89.7	1695.3
6	do.	do.	77	32.	960	48.	912.
7	do.	do.	77	32.5	975	48.7	926.3
8	do.	do.	77	32.5	975	48.7	926.3
9	do.	do.	77	33.5	1005	50.2	954.8
10	do.	do.	77	33.5	1005	50.2	954.8
11	do.	do.	77	34.5	1035	51.7	983.3
12	do.	do.	77	35.	1050	52.5	997.5

TABLE CII.

{ *of each size, broken up cold, and without annealing, the others annealed and cooled, either in cinders or in water.*

Strength in lbs. per square inch.	Mean strength in each state.	REMARKS.
73379		The first five experiments were made on specimen 199 B, of the wire, unannealed.
73379		
74880		
74386		
73379		
	73880	
49760		This and the four following experiments were made on a specimen of the wire of about the same length as the above, annealed by heating to redness, and then buried in dry ashes until cold.
54786		
62323		
61819		
61819		Broke in the gripe of the wedges.
	58101	
52268		This and the four following were made on a specimen of the same wire as the two above mentioned, annealed at redness and immediately quenched in cold water.
53781		
52775		
54281		
54786		
	53578	
89469		This and the four following experiments, were on the smallest size of wire, 199 C., in its unannealed state.
89469		
88703		
89469		
88703		
	89162	
47714		This and the two following were made on wire of the same size, and from the same piece as the above, annealed and buried in ashes.
48360		
48360		
	48144	
49958		This and the three following were on the same size of wire, annealed and immediately quenched.
49958		
51449		
52192		
	50889	

No essential change of specific gravity from annealing was detected, except in the case of a piece which had been beforehand excessively hammer-hardened. This appeared to have been slightly diminished in density by the annealing process. When the specimens treated in this manner had been previously strained nearly to the limit of their tenacity, and their original areas of section consequently much reduced, the precaution was taken to re-gauge them before annealing, so that we could employ the then existing areas of section, instead of the original ones, as the basis of calculation for the strength per square inch. This course was followed with Nos. 224 C and 224 D.

Calculating the strengths on the areas of these bars taken just before annealing, they were found as follows:

Instead	of	36052	we	obtained	45090,
"	"	39333	"	"	41980,
"	"	35889	"	"	42700,
"	"	36706	"	"	43200,
"	"	38676	"	"	41980.

From table CI. it appears, that, computing the strength in the comparisons from 11 to 15 inclusive on the area before annealing, and excluding Nos. 1 and 3 of the series, as not made at a sufficiently high temperature to effect the purpose, we get the mean tenacity of iron, by seventeen comparisons after annealing, equal to 45117 lbs. to the square inch.

In a considerable number of cases where trials were made at high temperatures, especially those above 1000°, the iron was left in an annealed state. In several of these the effect of the process is nearly as striking as where the heating had extended to the point of welding.

In other cases the difference between the strength previous to annealing, and that exhibited afterwards, was so small, that it was difficult to refer it to any other cause than the original inequalities of structure.

It will be seen that, from Experiment 3 to Experiment 11 (Table CI.) the loss of tenacity by annealing follows very nearly the order of the temperatures at which the process was performed.

That boilers do, in the course of ordinary practice, frequently become annealed there can be little doubt. The four specimens of old boiler-iron already spoken of, indicate clearly the existence of such a state. The mean strength of those specimens by 15 experiments was 49278 lbs., while the mean minimum strength of the four bars was 46252, quite within the range of the tenacity of iron annealed at a red heat. Hence, unless we can be certain that a boiler will be entirely secure from this process, we shall not be warranted in calculating its strength at any greater amount than about 46000 pounds per square inch, and of this amount but two-thirds can be assumed as a safe basis of calculation, being that at which permanent change of form would take place.

Your sub-committee have at length brought to a conclusion the research which has so long* occupied their attention. The foregoing pages present as concisely as the case seemed to admit, the facts which their investigations have elicited, in regard to the several inquiries, Principal, Incidental and Subsidiary, stated in the preliminary part of this report. The great interest of the subject required that the utmost care should be

* This sub-committee was appointed January 4, 1831, and preparations for the experiments immediately prosecuted.—The trials of tenacity were commenced April 4, 1832. The last experiments were made January 5, 1837.

exercised to prevent error. Hasty and unwarrantable conclusions were to be avoided. It has been our sincere desire to meet every just expectation in regard to the practical usefulness of the information of which we were in search. It would be presuming too far to suppose that in so extensive a mass of calculations we had escaped all error. So many steps of each process, have, however, been preserved, that verifications will be easily made. Speculations, merely scientific, have been deemed inappropriate to this report, and we now abstain from swelling it with repetitions of statements already made, or with any matters not strictly pertinent to the subjects embraced within the views of the general committee.

WALTER R. JOHNSON.
BENJAMIN REEVES.

N. B.—Prof. A. D. BACHE, the remaining member of the sub-committee, being absent from the country at the time of making this report, we regret that it is impracticable to submit it to him for inspection and signature.

In the course of this inquiry we have been indebted for valuable personal assistance to several friends of the useful arts, among whom we would particularly mention the late BENJAMIN SAY, Esq., and Messrs. JAMES M'CREA, JAMES BARNET and JOSEPH BREZINSKI. The last named gentleman repeated and verified many of the calculations as well as aided in various experiments

NOTE.—Mr. Telford has made an interesting series of experiments on the strength of wire, an account of which is found in Mr. Barlow's treatise on the strength and stress of timber, page 254.

The same gentleman made various experiments on bars and bolts of iron, detailed in the same work.

He also attended to the successive elongations of bars under different weights, and noted the amount of recoil or contraction when relieved from strain.

Captain S. Brown has also furnished to Mr. Barlow, a series of highly interesting experiments on the strength and elongation of iron bolts.

The mean result of three experiments by Mr. Brown on cast-iron was 18564 lbs. to the square inch.

Mr. Hodgkinson has published in the third report of the British Association, three results of experiments on the same material, which make its strength 17136 lbs. per square inch, while the three experiments of the committee of the Frank. Inst., which were considered fair, indicated in the bars a strength of 20834 lbs.

Mr. Brunton and Mr. Brunel, have each engaged in this interesting department of inquiry and given the results of experiments on a large scale which will be found in the work of Mr. Barlow already cited.

Mr. E. Martin, formerly of the Polytechnic school, has given in the Annales des Mines, Vol. V., a series of experiments executed in France, under the orders of M. Barbé, on round rods of iron, 18 or 19 feet long and 2 inches or more in diameter, made with a view, in part, to determine the recoil when released from strain, and the actual amount of elongation under each weight to which it was subjected.

In the same volume of the Annales des Mines, M. Vicat has a paper referring to, and controverting some of the positions of M. Martin, but not affecting the statements respecting the experimental operations just referred to.

In the same work, Vol. VI., are contained some interesting statements by M. Payen, respecting the manufacture of wire, in which the relative ductility before and after annealing is established.

In the Annales de Chimie et de Physique for Sept. 1833, is a valuable paper by M. Vicat, showing the influence of time on the gradual extension of wires under different weights. Each of his experiments occupied nearly three years.

The quantity by which iron extends under different degrees of tension, and on the recoil when relieved from strain, has been examined by Prof. Barlow. See Journal Fran. Inst. Vol. XVI. p. 124, &c. The relation between the effect of straining and elongating a bar by mechanical means, and that of expanding it by heat, is also noticed.

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